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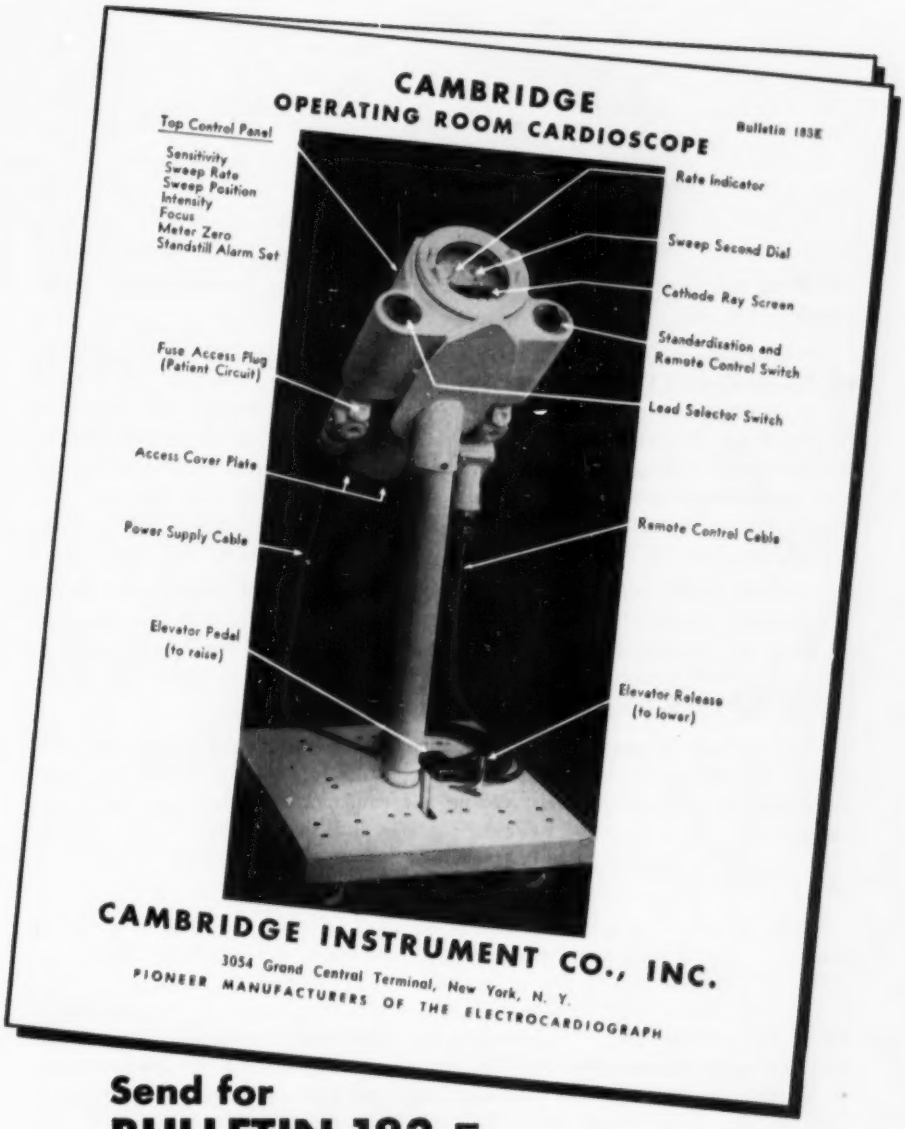

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The use of the seal has several functions: Being a circle in design, it relieves to an extent the over-all use of lines, squares, and rectangles; it stands as a symbol for the many years of dedicated service by an organization of the American Medical Association's stature in the advancement of knowledge in specialized fields, thus adding immeasurably to the effectiveness of the design.

The change in page format is confined to the title, subtitle, and authors' names. The change from a Coronet Bold type face to Bodoni Bold will eliminate the difficulty encountered when reading a formula or an abbreviation in script capitals. The use of Antique Italic for subtitles and Spartan Bold for the authors creates a desirable distinction between these parts. The arrangement realizes a saving in space.

This new cover is a development of an idea. It is not the result of a sudden thought. First, a suggestion was presented which was nothing more than a different arrangement of familiar elements. Then followed the collection of reactions, suggestions, and additional experimentation in search for the inspiration. All of the separate bits of information gathered were thoroughly digested, and the relationship between elements was established. The result is the crystallization of the idea. In following this procedure, our readers and editors have contributed immeasurably to the end product. Their cooperation means a new design of lasting quality.

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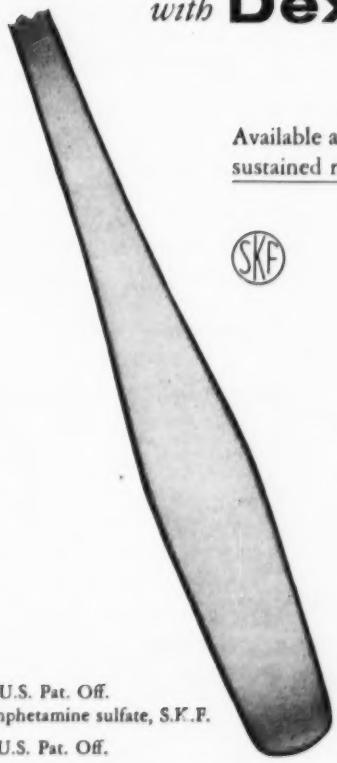

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A.M.A. ARCHIVES OF
SURGERY

Training of a Vascular Surgeon

ALTON OCHSNER, M.D., New Orleans

No branch of surgery has advanced as much in the past decade as has surgery of the vascular system. Prior to a decade and a half ago, surgery of the vascular system consisted of ligation of bleeding vessels; correction of peripheral aneurysms by ligation, exclusion, or partial excision; correction of venous abnormalities; removal of vascular tumors, and decortication of the heart for constrictive pericarditis and repair of heart wounds. For the performance of these procedures it was necessary that the surgeon be well trained in surgical techniques generally and possess courage to treat certain vascular tumors and aneurysms. Tremendous impetus was given to vascular surgery by the fundamental investigations of Carrel on arterial suture and the clinical observations and treatment of aneurysms by Matas in which the relatively conservative procedure of endoaneurysmorrhaphy was employed. It is remarkable, however, that very little fundamental advance was made in surgery of the vascular system from the original investigations of Carrel and Matas until recently.

Attempts to increase the vascularity of the heart by procedures to promote new vascular channels in the myocardium have been made possible by the researches of Beck,[1,2] O'Shaughnessy,[3] and Vineberg.[4] Closure of a persistent communication between the systemic and pulmonary circulations in ductus arteriosus by Gross[5] in 1938, successful excision of the narrowed portion of aorta in coarctation by Gross[6,7] and Crafoord,[8] and reestablishment of continuity either by direct suture or by use of a homograft marked a new era in the development of surgery of the vascular system. Blalock[9] and Potts[10] suggested that the inadequate oxygenation in tetralogy of Fallot could be relieved by surgically producing a shunt between the systemic and pulmonary circulations. This was the origin of the treatment of congenital anomalies of the heart. The correction of congenital and acquired anomalies of the heart by intracardiac procedures as elaborated by Brock,[11] Potts,[12] Harken,[13] Bailey,[14] Glover,[15] Gross,[16] Bigelow,[17] Swan,[18] Lillehei,[19] Gibbon,[20] Dennis,[21] Dodrill,[22] Kirklin,[23] and many others represented tremendous advances in the treatment of intracardiac anomalies. The development by Hufnagel[24] of a plastic valve for insertion into the aorta to reestablish the valve mechanism has rehabilitated and prolonged the lives of many unfortunate persons with aortic valve insufficiency.

In 1940 Leriche[25] described a syndrome which bears his name in which there is localized arteriosclerotic obliteration of the distal aorta and for which he advocated arteriotomy and extirpation of the diseased aortic intima (endarterectomy). The differentiation of the two major types of venous thrombosis and the elaboration of appro-

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priate therapy in each has represented an advance.[26] The more recent correction of acquired lesions of the aorta, as a result of either arteriosclerotic or syphilitic change, by resection of almost any part of the aorta and its replacement by either homograft or plastic material, has been made possible by the investigations of DeBakey and his coworkers,[27] Bahnson,[28] Deterling,[29,30] Blakemore [31] and others.

Practically all of these great advances in vascular surgery, with the exception of vascular suture, repair of cardiac wounds, and the relatively conservative treatment of aneurysms, have been made in the past decade. What factors have been responsible for these tremendous advances, and for the development of procedures which have become more or less commonplace in the treatment of anomalies which previously defied any attempt at correction? These have been possible almost entirely because of one factor, namely, the broadening of the training of the surgeon who is interested in vascular surgery. Although any surgeon must be well trained in the fundamentals of surgery, that is, the necessity of handling tissues as atraumatically as possible, the understanding of the normal histologic processes of wound healing, and the care of the patient generally, the vascular surgeon must not only be grounded in these facets of general surgery but must, in addition, be trained to perform operative procedures within the abdomen and the thorax and on the extremities. In addition, he must be an experimentalist and a physiologist, more familiar than his colleagues with the disturbed physiology produced by vascular anomalies. Whereas previously it was possible for a surgeon to become adept and competent by hospital and out-patient training, through which he became adequately grounded in pathology, anatomy, and surgical diagnosis and obtained considerable experience in operative therapy, these are not sufficient in the training of a vascular surgeon. It is imperative that a vascular surgeon spend a great deal of time in the experimental laboratory, not only because he can become adept in a way that is impossible by working only in a hospital but also because he can anticipate and solve problems which might not be possible in the wards and the operating rooms of a hospital. Ravdin [32] states, "Recent additions to pulmonary, cardiac, and vascular surgery have been possible because of an intimate knowledge of normal physiologic function, and the surgery of these systems has a rational and sound foundation. The surgeons who have explored and are continuing to expand these fields, could not have attained the brilliant results which they have, however great their technical skill, had they not been able to utilize the fundamental knowledge which investigators in the basic sciences have made available." Experimental research and performance of many operations upon animals make possible the development of the present-day vascular surgeon, and no greater satisfaction could be had by those who have had the foresight to envision this than the sense of having accomplished what previously seemed impossible.

Because of the necessity that a vascular surgeon should be much more adequately trained in the fundamental branches of medicine than is required in many other branches of surgery, it is desirable that he spend possibly a year or more in internal medicine, limiting his time almost entirely to the study of the vascular system. In addition to this, he should spend one or more years in a department of physiology or a surgical experimental laboratory in which considerable physiologic research is conducted, where he not only becomes familiar with the physiologic techniques but also learns to appreciate their values and limitations. Moreover, after embarking on the clinical phase of his training, it is essential that he continue to spend considerable time in the research laboratory, because it is only by frequently returning to the laboratory that he can solve additional problems.

In no branch of surgery is teamwork so important as in vascular surgery. Although

some of the older surgeons were very proud of the fact that they were able to perform an operation with the help of only one person and with the availability of very few instruments, such is not possible in the performance of most of the vascular surgical procedures. It is essential that most, if not all, members of the team work together in the experimental laboratory, because, although in the performance of most surgical procedures speed is not of particular importance, it is extremely desirable that the operative procedure for the correction of vascular anomalies should be accomplished within as short a time as possible. Although speed can never compensate for careful work, many vascular operations have been unsuccessful because the procedure required too much time. Only by the development of excellent teamwork can the operation be performed with absolutely no waste of movement or time.

Probably because it is relatively new as well as dramatic, vascular surgery has become extremely popular, and as a result there are many who desire to undertake it. However, patients with cardiovascular anomalies require extremely careful preoperative study and their diagnostic and functional evaluation is possible only in expensively equipped laboratories staffed by highly trained personnel who are not available in many institutions. Because of this, and also because of the necessity for the availability of, and continued investigation in, an experimental laboratory, as well as the need for a competent team accustomed to working together, it is probable that the treatment of complicated vascular anomalies should be limited to the larger centers and will not or, at least, should not be done by a surgeon who, although he is thoroughly competent as a general surgeon and is even thoroughly trained in surgery of the vascular system, cannot competently care for complicated cardiovascular anomalies.

However, it is possible and probable that in the not too distant future, with the development of better hospitals in smaller communities, which will undoubtedly attract well-trained physicians, experimentalists, and surgeons to these smaller comunities, vascular surgery even of the more complicated types can be performed safely in the smaller community. Until such facilities, including those of research and experiment, are available, by necessity, it is essential that complicated vascular cases should be treated only in those areas where the best care can be given to the person with these complicated anomalies.

Vascular surgery represents the last frontier in the development of surgery. Although there are many of you younger members who think of the present accomplishments in vascular surgery as being quite commonplace, to those of us who have seen the developments in the past quarter of a century it is indeed a remarkable accomplishment.

The members of the International Society of Angiology have done much to develop the field of modern vascular surgery, and the Society can be justly proud of the accomplishments of its members.

Prytania and Aline Sts. (15).

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Digital Blood Flow Following Reconstructive Arterial Surgery

OSCAR CREECH Jr., M.D.; MICHAEL E. DeBAKEY, M.D., and RALPH CULOTTA, M.D., Houston, Texas

The gratifying results obtained with reconstructive surgery of the aorta and peripheral arteries in the treatment of occlusive lesions is evidence of restoration of blood flow toward normal.[1-6] In general, clinical methods are adequate to assess the degree of change following resection or bypass of an occluded artery; however, it seemed to us that a quantitative measurement of the alteration produced by the disease on the one hand and by its operative correction on the other would provide interesting data relating to peripheral blood flow which might be clinically useful as well. This study was begun, therefore, to measure digital blood flow in the upper and lower extremities of patients with arteriosclerotic occlusive disease and aneurysms of the aorta and peripheral arteries. From among 25 patients in whom digital blood flow measurements were made, 9 have been selected to illustrate certain aspects of the study, and the data from these 9 cases comprise the material for this preliminary report.

Materials and Methods

Among the nine cases there were four with arteriosclerotic occlusion of the abdominal aorta, in two of which occlusion was complete and in two, incomplete. There were two cases of aneurysm of the abdominal aorta and three cases of arteriosclerotic occlusion of the femoral artery. All of the patients were men in the sixth and seventh decades.

Measurements of digital blood flow were made plethysmographically after the method described by Burch.[7,8] A digital electroplethysmograph sensitive to a volume change of 0.1 cu. mm. or less, and recording through a Sanborn direct-writing electrocardiographic machine was employed.[9] Occlusion of digital venous outflow was accomplished by means of a pneumatic cuff placed immediately proximal to the plethysmographic cup. The pressure used to inflate this cuff was always less than the diastolic arterial blood pressure and generally about 60 mm. of Hg.

In each case digital blood flow was measured before and at intervals after operation, and in two instances continuous recordings were made during operation. Subjects were conditioned for the study by a simple explanation of its purpose and the methods to be employed. Vasodilatation was induced by oral administration of 2 fluid ounces (60 cc.) of whiskey and by covering the patient with a blanket for 30 minutes prior to the study. If peripheral vasoconstriction was still present, preventing satisfactory measurement of the digital pulse wave, the study was abandoned and repeated at another time. Studies before and after operation were made in an air-conditioned room at 76 F $\pm$ 1. The temperature in the operating room was 72 F $\pm$ 1.

All measurements were made with the patient lying recumbent with the digits at heart level. In each instance curves of the volume-time course for the second right finger tip and for both right and left second toe tips were recorded. The volume artifact produced by the method employed was determined as previously described by Burch. This volume was then subtracted from the recorded trace for each digit after venous occlusion. The resulting value represented the volume of arterial inflow. Mean volume flow was then determined by measurement of the area under the curve, using Simpson's rule and is expressed as cubic millimeters per 5 cc. of part per second.

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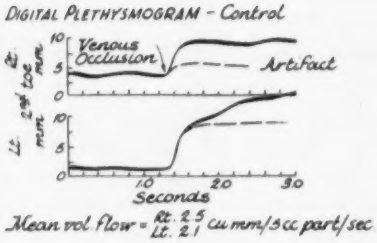


Fig. 1.—Digital plethysmogram prior to operation in Case 1. Complete occlusion of the aorta at the bifurcation is shown in the accompanying aortogram.

Illustrative Cases

1. Complete Aortic Occlusion

CASE 1.—A 63-year-old man was admitted to the hospital complaining of weakness of both lower extremities and a walking tolerance of only one block. Physical examination revealed a blood pressure of 180/70 mm. of Hg. There were no pulses in either lower extremity. Aortogram disclosed narrowing of the abdominal aorta with complete occlusion at the bifurcation (Fig. 1). Plethysmographic studies revealed a mean volume flow of 2.5 cu. mm. in the right second toe tip and 2.1 cu. mm. in the left second toe tip (Fig. 1). At operation the abdominal aorta was found to be completely occluded at the bifurcation, with severe atherosclerotic changes extending upward to the origin of the inferior mesenteric artery. The right common iliac artery was completely occluded, and the left was partially occluded. The aortic bifurcation was resected and replaced with a knitted Orlon prosthesis. Following anesthetization and throughout operation the volume-time course for right and left second toe tips was continuously recorded, and at frequent intervals volume inflow following venous occlusion was also determined (Fig. 2). Following administration of a spinal anesthetic there was no change in volume flow in the right second toe but there was an increase in blood flow in the left second toe tip. Application of an occluding clamp to the aorta above the inferior mesenteric artery reduced mean volume flow by half, and upon resection of the aortic bifurcation volume flow was reduced to zero. Upon completion of the proximal aortic and right common iliac anastomoses digital flow was again determined, and a striking increase in the values for both right and left toe tips was observed, although continuity of the right iliac artery only had been restored. Upon completion of the left iliac anastomosis the volume flow for the second digit of that extremity increased further, and it was observed that the volume flow for the right second toe tip had diminished. This vessel was inspected and found to be thrombosed at the site of

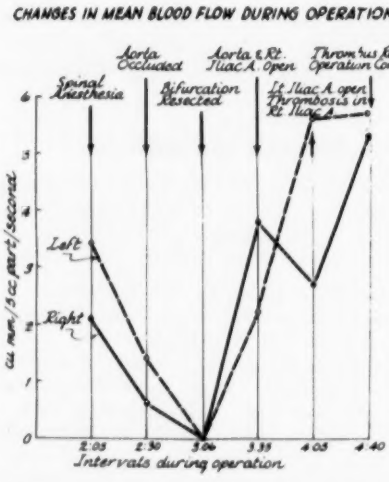


Fig. 2.—Changes in mean volume flow in the right and left second toe tips during operation in Case 1.

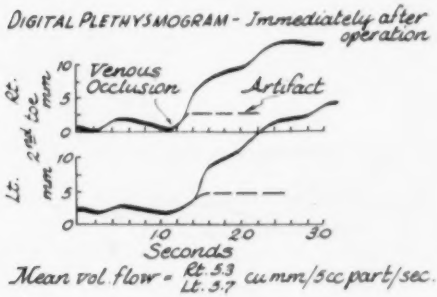


Fig. 3A.—Digital plethysmogram about 24 hours after operation in Case 1, showing a significant increase in digital blood flow.

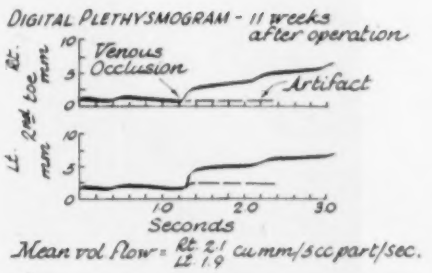


Fig. 3B.—Eleven weeks after operation digital blood flow had returned to preoperative levels.

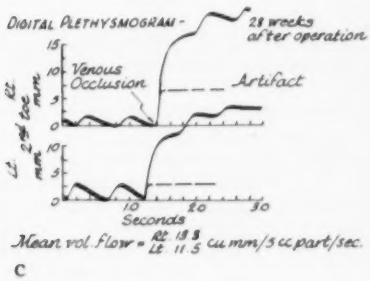


Fig. 3C.—Twenty-eight weeks after operation the digital plethysmogram was relatively normal, and aortogram disclosed normal patency of the aortic bifurcation and the iliac arteries.

anastomosis. Removal of the thrombus and repair of the anastomosis restored blood flow to the level observed immediately prior to thrombosis.

Twenty-four hours after operation mean volume flow in the second toe tips was 5.3 and 5.7 cu. mm. respectively (Fig. 3A). The postoperative course was uneventful, and the patient was discharged entirely free of symptoms. He returned to the hospital for reexamination approximately three months later, at which time plethysmographic studies were again performed (Fig. 3B). It was observed at this time that the mean volume flow had decreased to the preoperative level. Clinically pedal pulses were still present but did not appear to be as strong as on previous examinations. The studies were repeated seven months after operation and revealed a significant increase in digital blood flow (Fig. 3C). The patient stated that he was considerably improved over any previous occasion. Aortogram disclosed slight indentation at the suture lines but relatively normal patency of the Orlon prosthesis. The blood pressure, which prior to operation was 180/70 mm. of Hg, was reduced to 110/68 mm. of Hg following operation.

Comment.—The increase in digital blood flow occurring seven months after operation compared with a low flow earlier suggests that restoration of peripheral circulation may occur gradually after restoration of arterial patency. The studies made during operation are particularly interesting in that they demonstrate (1) the value of collaterals arising from the aorta in the region of the bifurcation and (2) the importance of the hypogastric arteries as collateral channels for the contralateral extremity.

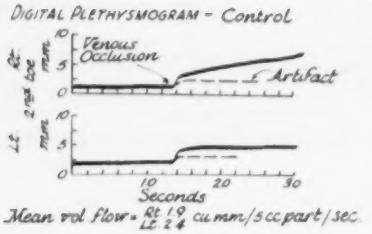


Fig. 4.—Digital plethysmogram prior to operation in Case 2. Complete aortic occlusion extending to the level of the renal arteries is shown in the accompanying aortogram.

CASE 2.—A 59-year-old man was admitted to the hospital with a history of intermittent claudication involving the hips, thighs, and buttocks for approximately one year. These symptoms had increased in severity to the point where he was able to walk only with the aid of crutches. Physical examination revealed no pulses in the lower extremities and a systolic murmur at the level of the umbilicus. The blood pressure was 180/100 mm. of Hg. Aortogram revealed complete occlusion of the abdominal aorta extending to the level of the renal arteries, and it appeared that the central portion of the thrombus extended above this point (Fig. 4). Digital plethysmography disclosed a mean blood flow of 1.48 cu. mm. in the right second toe and 1.81 cu. mm. in the left second toe (Fig. 4). By comparison, the mean volume flow for the second right finger tip was 8.8 cu. mm., a relatively normal value by the methods employed.

At operation the occlusive process was found to extend about 5 cm. proximal to the renal arteries and required occlusion of the aorta above the superior mesenteric branch in order to remove the thrombotic process completely. The common and external iliac arteries were completely occluded throughout their length. The abdominal aorta below the renal arteries was resected, and an aortic bifurcation homograft was anastomosed to the aorta above and to the common femoral arteries below. A left lumbar sympathectomy was done for the purpose of evaluating the effect of this procedure following restoration of blood flow by comparison with the opposite lower extremity, which had not been denervated.

There was an immediate return of pulsations to the dorsalis pedis and posterior tibial arteries bilaterally. The patient's postoperative course was uneventful, and two weeks after operation digital plethysmography was repeated. Significant improvement was observed in the right lower extremity, with a mean volume flow of 13.0 cu. mm. (Fig. 5). On the left, however, there was only slight improvement, the volume flow being 2.4 cu. mm. Two and one-half months after operation studies were again performed and revealed a decline in mean volume flow to 4.2 cu. mm. and 2.9 cu. mm. for the right and left second toe tips,

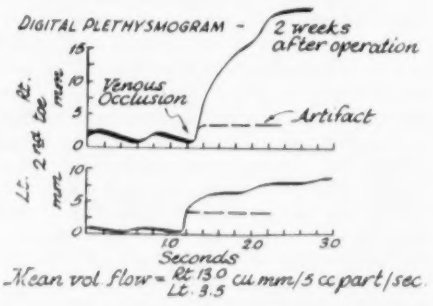


Fig. 5.—Digital plethysmogram two weeks after operation in Case 2, showing a relatively normal digital blood flow in the left lower extremity and little alteration in blood flow in the right lower extremity.

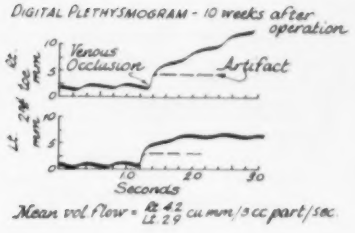


Fig. 6.—Digital plethysmogram 10 weeks after operation in Case 2, showing a reduction in digital blood flow toward preoperative levels. Normal patency of the aortic and iliac arterial grafts is shown in the accompanying aortogram.

respectively (Fig. 6). At this time the blood pressure was 116/88 mm. of Hg, and the patient was able to walk without symptoms except for slight discomfort in the left calf.

Comment.—The slight increase in mean volume flow in the left foot following restoration of aortic continuity as compared with the substantial increase in the right foot suggests the presence of more advanced arteriosclerotic occlusive disease in the vessels of the left lower extremity. The reduction in digital blood flow on the right three months after operation is similar to that observed in Case 1. Similarly, there was a marked reduction in blood pressure from 180/100 mm. of Hg to 116/88 mm. of Hg. Additional studies are planned to determine whether this reduction in digital blood flow is temporary or is an indication of progressing occlusive disease of the peripheral arteries. It is interesting to note that left lumbar sympathectomy failed to improve blood flow in the lower extremity.

2. Partial Aortic Occlusion

CASE 3.—A 58-year-old man was admitted to the hospital with a seven-year history of progressive weakness of the back, hips, and legs, with coldness of both feet. Physical examination disclosed a blood pressure of 130/80 mm. of Hg. There was weak femoral pulse on the right, but all other lower extremity pulses were absent. An aortogram revealed narrowing of the terminal aorta in the region of the bifurcation and complete occlusion of the left common iliac artery (Fig. 7). Femoral arteriograms demonstrated relatively normal patency of the peripheral arterial system. Plethysmographic studies disclosed a mean volume flow in the right and left second toe tips of 1.95 and 1.7 cu. mm., respectively (Fig 7).

At operation the occlusive process was found to extend to the level of the inferior mesenteric artery above and to the bifurcation of the left common iliac artery below. The aortic bifurcation was resected and replaced with a homograft. Upon completion of the procedure there was immediate return of pulses to the dorsalis pedis and posterior tibial vessels bilaterally. The patient's postoperative course was uneventful, and following discharge he has remained entirely asymptomatic. Plethysmographic studies performed one week after operation revealed little alteration from preoperative determinations (Fig. 8A). However, five weeks after operation volume inflow in the lower extremities had increased to 6.4 cu. mm. in the right and 7.5 cu. mm. in the left second toe tips (Fig. 8B).

Comment.—The failure to show an increase in digital blood flow one week following restoration of aortic continuity in the

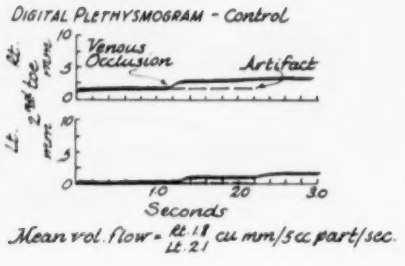
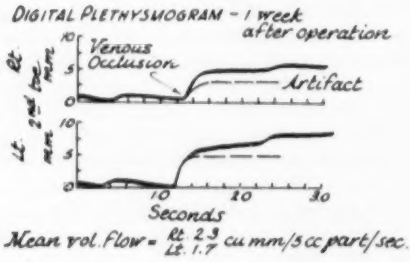


Fig. 7.—Digital plethysmogram prior to operation in Case 3. Partial aortic occlusion with complete occlusion of the left common iliac artery is shown in the accompanying aortogram.

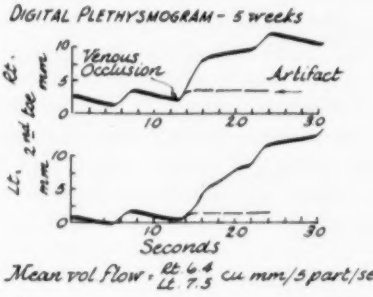
presence of strong pedal pulses simply reflects the vasoconstriction resulting from discomfort incident to operation. Five weeks later the patient was asymptomatic, and digital blood flow had increased significantly.

CASE 4.—A 58-year-old man was admitted to the hospital complaining of cramping pain in both lower extremities of six to seven years' duration, with a walking tolerance of only one block. Three years previously a left lumbar sympathectomy had been performed, with slight improvement in symptoms on that side. Physical examination revealed a blood pressure of 140/80 mm. of Hg. There were no palpable pulses in the left lower extremity, although all pulses were weakly present on the right. An aortogram revealed narrowing of the terminal aorta, with complete occlusion of the left common iliac artery. Plethysmography disclosed mean volume flows of 1.2 and 2.75 cu. mm. in the right and left second toes, respectively. At operation the occlusive process was found to be much more extensive than was indicated by aortography in that the right common and external iliac arteries were almost completely occluded throughout their length, and in addition to complete occlusion of the left common iliac artery the left external iliac artery was severely involved. An



A

Fig. 8A.—Digital plethysmogram one week after operation in Case 3, showing little alteration in digital blood flow compared with determinations made prior to operation.



B

Fig. 8B.—Five weeks after operation mean blood flow in the right and left second toe tips had significantly increased.

onlay graft was utilized, anastomosing the upper end of the homograft to the anterior surface of the abdominal aorta just below the inferior mesenteric artery and the end of each external iliac portion of the graft to the side of the common femoral artery below. Upon release of the occluding clamps, pulsatile blood flow was restored to both feet. On discharge from the hospital the patient was considerably relieved of symptoms. About five weeks after operation plethysmographic studies were repeated and disclosed little alteration in digital blood flow. At this time the patient was only partially ambulatory and had not completely recovered from operation. Six months after operation digital blood flow had increased to 5.9 and 5.7 cu. mm. for the right and left second toe tips, respectively, and he was able to walk indefinitely without symptoms.

Comment.—The results in this case are similar to those in the previous case in that improvement in digital blood flow apparently occurred slowly, although pedal pulses were palpable immediately after operation. It is of interest to note that prior to operation volume flow was greatest in the left second toe tip, the side on which lumbar sympathectomy had been performed previously, although pulses were absent in this extremity and present in the opposite limb. However, six months after operation blood flow in the digits of both lower extremities was equal.

3. Abdominal Aneurysm

Case 5.—A 60-year-old man was admitted to the hospital complaining of a painful pulsating abdominal mass of three months' duration. Physical examination disclosed a blood pressure of 100/60 mm. of Hg. and a large pulsating mass extending from the xiphoid to the umbilicus. All pulses were present and equal in both lower extremities. Prior to operation plethysmographic studies revealed mean volume flows of 1.45 and 1.77 cu. mm. in the right and left second toe tips, respectively. This determination was not entirely satisfactory, since there was evidence of considerable vasospasm despite attempts to correct this phenomenon. At operation a large aneurysm was found extending from just below the renal arteries to the common iliac arteries. The aneurysm was resected and replaced with an aortic homograft. A continuous trace of the pulse wave was made throughout operation, beginning after induction of anesthesia, and at intervals the volume flow was determined by the venous occlusion method. (Fig. 9). After anesthetization there was

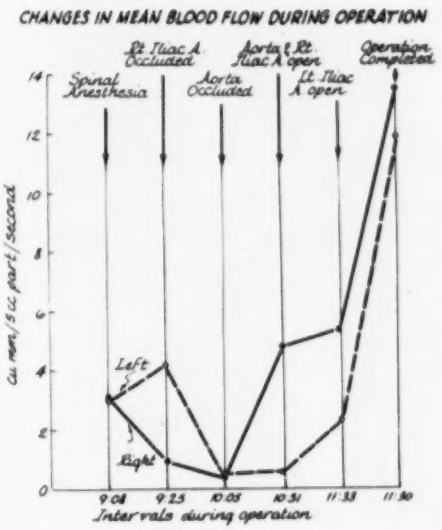


Fig. 9.—Changes in mean volume flow in the right and left second toe tips during operation in Case 5. There are striking differences between values obtained for digital blood flow in this case and in Case 1 (Fig. 2).

an increase in pulse volume and of mean volume flow in the digits as compared with the preoperative determinations, which represented abolition of vasoconstrictor impulses. Upon application of occluding clamps to the aorta and common iliac arteries, digital blood flow fell to zero. After completion of the aortic and right common iliac anastomoses and upon release of the occluding clamps blood flow in the right second toe tip increased significantly, but that in the left was unaltered. Upon completion of the left iliac anastomosis the volume flow into left second toe tip increased, and at the end of operation mean volume flows for both right and left second toe tips had reached high normal values.

Upon completion of the operation pulses were present in dorsalis pedis and posterior tibial arteries bilaterally. The patient's postoperative course was complicated by the development of iliofemoral thrombophlebitis in the left lower extremity, which subsided on conservative therapy. Plethysmography one month after operation revealed no alteration in digital blood flow over that observed prior to operation. However, at this time the patient was not entirely recovered from operation, and there was considerable peripheral vasoconstriction evident.

Comment.—The plethysmographic studies before and after operation are not entirely satisfactory because of the peripheral vaso-

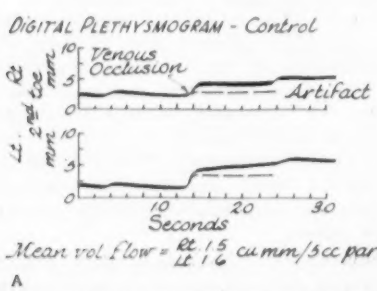
constriction which existed. That this was a factor is indicated by the increase in pulse volume and volume inflow after induction of anesthesia. Of particular interest is the fall in volume flow to zero upon occlusion of the aorta. As indicated previously in Case 1, an example of complete aortic occlusion, application of occluding clamps to the aorta produced only moderate alteration in digital blood flow, demonstrating the degree to which collateral circulation is developed in patients with occlusive lesions as compared with the lack of its development in those with aneurysms. Similarly, in the case of aortic occlusion, when blood flow was restored to the right iliac artery there was a corresponding increase in blood flow to the left second toe tip as a result of extensive collateral circulation primarily through the hypogastric arteries. On the other hand, in this case restoration of blood flow to the right lower extremity produced no alteration in digital blood flow on the left and is further evidence of the paucity of collateral circulation developing in patients with aneurysms. The high mean flows observed at the end of operation may have been evidence of reactive hyperemia resulting from temporary complete aortic occlusion.

Case 6.—A 61-year-old man was admitted to the hospital for treatment of an abdominal aneurysm discovered six weeks previously during a routine physical examination. There were no symptoms. Physical examination revealed a blood pressure of 170/100 mm. of Hg. There was evidence of severe generalized arteriosclerosis, and a large pulsating mass was palpable in the abdomen just to the right of the midline. Peripheral pulses were present and equal bilaterally. Roentgenograms of the abdomen disclosed a large fusiform aneurysm of the abdominal aorta with extensive calcification in its walls. Plethysmography revealed a mean volume flow in the toe tips of 1.6 and 1.5 cu. mm. in the left and right, respectively (Fig. 10A). At operation the aneurysm was resected and replaced with a bifurcation aortic homograft. The postoperative course was without incident, and just prior to discharge plethysmographic studies were repeated. At this time there was a significant increase in pulse volume and mean volume flow (Fig. 10B).

Comment.—Gross examination of the specimen removed at operation disclosed changes characteristic of arteriosclerotic aneurysms of the abdominal aorta. In places the lumen was increased threefold, while elsewhere it was severely narrowed by thrombotic material. These luminal changes produced a significant reduction in peripheral blood flow, and following resection of the aneurysm and homograft replacement there was restoration of digital blood flow toward normal.

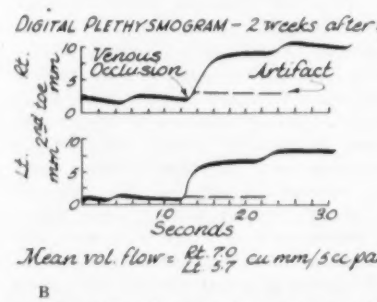
4. Arterial Occlusive Disease

Case 7.—A 58-year-old man was admitted to the hospital with a history of persistent pain in the lower back and weakness and fatigue in the left lower extremity for about one year. There had been a progressive decrease in sexual potency during the preceding five months. Physical examination disclosed a blood pressure of 170/100 mm. of Hg. There was a soft systolic murmur just to the left of the umbilicus. All pulses in the left lower extremity were weakly palpable, but those in the right lower extremity were relatively normal. An aortogram revealed partial occlusion of the common iliac artery at its bifurcation (Fig. 11). Plethysmograms revealed a dig-



A

Fig. 10A.—Digital plethysmogram prior to operation in Case 6.



B

Fig. 10B.—Two weeks after operation there was a significant increase in digital blood flow.

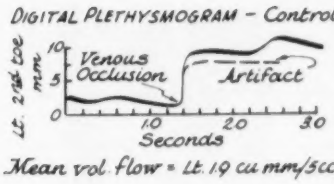
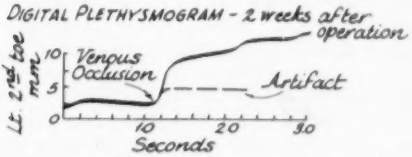


Fig. 11.—Digital plethysmogram prior to operation in Case 7. Partial occlusion of the common iliac artery at its bifurcation is shown in the accompanying aortogram.

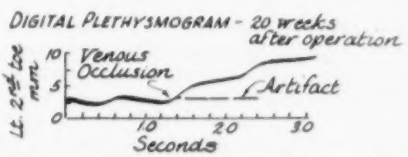
ital blood flow in the right second toe tip of 6.0 cu. mm. and 1.5 cu. mm. on the left (Fig. 11). At operation the aorta and right common iliac artery were found to be relatively normal; however, there was extensive disease of the left common and external and internal iliac arteries. A knitted Orlon prosthesis was anastomosed to the side of the common iliac artery above, 1 cm. distal to its origin, and to the side of the common femoral artery below. Upon completion of the procedure pulses were present in the left foot and appeared to be considerably increased in volume over those noted before operation. Two weeks after operation digital blood flow had increased in the left lower extremity to 6.1 cu. mm., and the patient was discharged from the hospital without symptoms (Fig. 12A). Five months after operation the patient was examined in the outpatient clinic, and pedal pulses of good volume were noted bilaterally. However, digital plethysmography at that time revealed a mean volume flow in the left second toe tip of 3.13 cu. mm. (Fig. 12B). Six weeks later, six and one-half months after operation, he returned complaining of pain in the left leg, and a further decrease in digital blood flow was observed (Fig. 13). When last examined in the outpatient clinic, nine months after operation, there was slight progression of the symptoms of the left lower extremity, but plethysmographic studies were not repeated.

Comment.—In this instance plethysmography demonstrated a progressive diminution in peripheral blood flow following initial early improvement after iliac artery bypass had been performed. Thus, five



A

Fig. 12A.—Digital plethysmogram two weeks after operation reveals a considerable increase in mean volume flow in the left second toe.



B

Fig. 12B.—However, 20 weeks after operation there was a reduction in digital blood flow toward preoperative levels, although the patient was symptomatically improved.

Fig. 13.—Digital plethysmogram 26 weeks after operation in Case 7 shows a return of mean volume flow to preoperative levels. Aortogram made at this time reveals patency of the iliac prosthesis but poor filling of the femoral artery below.

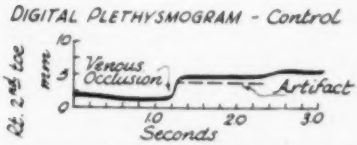
months after operation, in spite of palpable pedal pulses, plethysmography revealed a reduction in digital blood flow which was apparent clinically six weeks later. The continued decrease in peripheral blood flow noted at six and one-half months after operation was additional evidence of progression of the occlusive process beyond the area which had been bypassed at operation.

Case 8.—A 60-year-old man was admitted to the hospital with a five-year history of intermittent claudication of both lower extremities. Left lumbar sympathectomy had been performed previously, with no amelioration of symptoms. Physical examination revealed bilateral femoral pulses, although that on the left was severely diminished. Popliteal and pedal pulses were bilaterally absent. Femoral arteriograms disclosed a segmental block of each superficial femoral artery with patent popliteal segments distal to the obstruction. Digital plethysmograms disclosed a mean volume flow of 3.9 cu. mm. in the left second toe tip and 3.4 cu. mm. in the right. At operation the occluded segments were bypassed with arterial heterografts using end-to-side anastomoses.

Following operation pulses were restored to the left dorsalis pedis and posterior tibial arteries, but no pedal pulses were palpable on the right, and clinically the right lower extremity failed to show improvement. Two weeks after operation digital blood flow in the left foot was 5.7 cu. mm. and in the right, 2.2 cu. mm. One month after operation there was a further reduction of blood flow in the right lower extremity, mean volume flow for the second toe tip being 2.3 cu. mm. and for the left, 5.7 cu. mm.

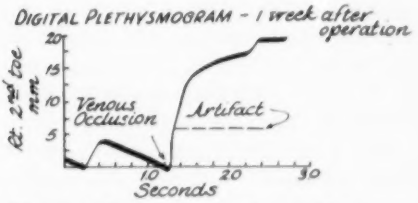
Comment.—This case is primarily of interest because it demonstrates a significant decrease in peripheral blood flow following an unsuccessful femoral bypass procedure, although clinically there was little change.

Case 9.—A 60-year-old man was admitted to the hospital complaining of severe intermittent claudication of both lower extremities of one year's duration. There was associated numbness and coldness of the right foot. Physical examination revealed generalized arteriosclerosis. The femoral pulses were strongly palpable bilaterally, and a faint posterior tibial pulse could be felt in each extremity. Femoral arteriograms revealed extensive atherosclerotic changes throughout the right superficial femoral artery, and in a segment about 6 cm. in length the lumen was almost completely occluded (Fig. 14A). On the left there was complete occlusion of the superficial femoral artery, with development of extensive collaterals by way of the profunda femoris. Plethysmographic studies revealed a volume flow of 1.3 cu. mm. in both the right and left second toe tips (Fig. 14A). At operation the right superficial femoral artery was bypassed with a crimped nylon tube, using end-to-side anastomoses to the common femoral above and to the popliteal artery below. Immediately a strong pulse was palpable in both dorsalis pedis and posterior tibial vessels in the right lower extremity. One week after operation digital plethysmography disclosed a significant increase in pulse volume and a mean volume



A

Fig. 14A.—Digital plethysmogram prior to operation in Case 9. Partial occlusion of the superficial femoral artery is shown in the accompanying arteriogram.



B

Fig. 14B.—One week after operation there was an increase in digital blood flow on the right to near normal levels.

flow of 9.6 cu. mm.. (Fig. 14B). Since operation the patient has been entirely free of symptoms.

Comment.—In this instance extensive atherosclerosis had encroached upon the lumen of the superficial femoral artery to such an extent that an effective pulse pressure could not be maintained distal to the atheromatous lesions, and it resulted in symptoms of ischemia, although a pulse was palpable in the posterior tibial artery. This is a striking example of the fact that symptoms of peripheral arterial insufficiency may exist in the presence of palpable pulses. The gratifying symptomatic improvement following the creation of a large collateral vessel in the form of a bypass is indicative of the restoration of an effective pulse pressure to the extremity distal to the occlusive process. This is confirmed by plethysmographic studies.

Comment

The principal sources of error inherent in digital plethysmography have been described in detail by Burch [1,2] and are essentially as follows: (1) position of the digit with reference to heart level, (2) the artifact due to position of the occluding cuff, (3) leakage of blood past the occluding cuff, (4) orienting and other vascular reflexes, (5) fullness of "venous reservoirs," and (6) environmental temperature and humidity. In performing this study, it was possible to control or correct for these factors before and after operation and to a smaller extent during operation. Other anatomic and physiologic factors, however, could not be entirely eliminated or compensated for and may have had a significant effect on the results. It is recognized that plethysmographic studies of the toes are more difficult than similar studies of the finger tip because of the shape and relatively short length of the toes, making it difficult to obtain an airtight seal about the plethysmographic cup and to apply the pneumatic cuff at the base of the digit. However, with experience and patience this part of the technique can be performed relatively satisfactorily. On the other hand,

variables related to cardiovascular hemodynamics and resulting from operation were difficult to control, and their effect on the early postoperative measurements of digital blood flow may have been significant. Thus, for patients having aortic resection and homograft replacement, relatively large quantities of whole blood were administered during and immediately after operation. The amount of blood given was based on clinical signs rather than on the more accurate methods of estimating blood loss, such as the gravimetric method or determination of total blood volume. Thus, it is entirely possible that in some cases a blood volume deficit existed at the time of study while in others blood volume was in excess of the preoperative level. As a result, blood viscosity, cardiac output, cardiac rate, and blood pressure may have been significantly altered, producing changes in digital blood flow unrelated to luminal restoration.

Pain and discomfort caused by the operative wound may also affect digital blood flow by producing reflex vasoconstriction. Although this phenomenon can be partially abolished by simple measures to induce vasodilatation, it must be considered when evaluating digital blood flow within the first month after operation.

Because of these variables, the values for mean digital blood flow recorded above cannot be considered accurate measurements even within the limits of the plethysmographic method and reflect gross alterations in digital blood flow only.

The observations made in Case 1 suggest a pattern of response to luminal restoration consisting of early reduction in digital blood flow with later increase toward normal levels. Thus, in the early period following operation digital blood flow remained near the levels observed prior to operation. At the same time the patient's clinical improvement was not striking. There had been an immediate reduction in blood pressure from 180/70 mm. of Hg before operation to 180/68 mm. of Hg following operation. By the seventh month, however, plethysmographic studies disclosed a significant increase in digital blood flow, and dramatic improvement in the patient's condition had occurred. Since that time improvement has continued, and the patient is now without symptoms.

The treatment of complete aortic occlusion by resection of the involved segment of aorta and replacement with a vascular substitute, thereby restoring a relatively normal lumen, raises some provocative questions regarding peripheral blood flow. During the period of complete occlusion of the terminal aorta, blood flow to the pelvis and lower extremities occurs by way of collateral vessels. That the total volume of blood delivered by these collateral channels is in excess of critical flows is evidenced by the usual normal appearance of the distal soft parts. That the volume flow is not normal, however, is evidenced by the development of symptoms of muscle ischemia. With sudden restoration of the lumen to major or primary arterial pathways the collateral vessels are no longer needed to the extent that they were required prior to operation. Whether the collateral arterial pathways continue to function and for how long a period of time is not clear. If the luminal diameter of these vessels is reduced gradually in response to the lack of demand and if primary arterial pathways are patent, it would appear that the "arterial reservoir" in the lower extremities is considerable augmented, and a relative blood volume deficit may result. Under these circumstances the effective pressure in the small arteries and arterioles would be reduced with a resultant reduction in peripheral blood flow.[7] In time an adjustment in the hemodynamics of blood flow in the lower extremities toward normal would take place, and with continued patency of the primary arterial pathways peripheral blood flow should return to normal.

On the other hand, patients with complete aortic occlusion frequently have arterial hypertension due to increased peripheral resistance of the collateral bed, and restoration of aortic lumen produces a significant lowering of blood pressure in most instances. The early reduction in peripheral blood flow

following restoration of aortic lumen, therefore, may be an indication that an area of high peripheral resistance, the collateral bed, has been supplanted by one of lower peripheral resistance, the primary arterial channels.

In the second case of complete aortic occlusion the changes in digital blood flow observed following operation were somewhat different from those in the previous case in that flows for the right second toe were significantly increased one month after operation, whereas those for the left lower extremity were only slightly increased. Clinically, pedal pulses were present bilaterally, although those on the left had a smaller volume than those on the right. Thus, it appears that there was some peripheral obstruction to blood flow on the left, which in part accounted for the reduction in digital blood flow on that side. Because of this peripheral obstruction more blood may have been shunted into the right lower extremity, thus partially neutralizing the effects of reduced blood pressure described above. On the other hand, the reduction in digital blood flow observed in this case at three months may be indicative of progressive arteriosclerotic occlusive disease in the peripheral vessels. Observation over a longer period of time will be required to determine the cause of these changes in peripheral blood flow.

In the two cases of partial aortic occlusion there was complete obliteration of the lumen of the left common iliac artery. Both patients experienced considerable wound pain, which persisted for almost a month after operation and precluded satisfactory plethysmographic studies during that time. However, in the first instance (Case 3) recovery was complete within one month, and at five weeks digital blood flow was greatly increased. In Case 4, however, the patient was not completely ambulatory at five weeks after operation and complained bitterly of soreness of the abdominal musculature. Plethysmographic studies at this time disclosed little change in blood flow. However, five months later the patient was completely recovered and had returned to work, and at this time peripheral blood flow was significantly improved. In this case a left lumbar sympathectomy had been performed three years before operation, and although there was a greater digital blood inflow in that extremity than in the right prior to operation, six months after operation blood flow was equal in both right and left second toe tips!

It has been observed that alterations in digital blood flow may precede clinical evidence of ischemia by a significant period of time. Thus, in Case 7 there was initial improvement in digital blood flow after operation for left iliac artery occlusion, but five months later a significant reduction had occurred, although at this time the patient was free of symptoms. Later, symptoms of ischemia appeared in the left leg, and there was plethysmographic evidence of further reduction in digital blood flow. This was confirmed by aortography, which disclosed a patent bypass prosthesis, with poor filling of the femoral artery below.

The technique of digital plethysmography has been found useful in assessing the effect of unsuccessful attempts to bypass an occluded segment of femoral artery. It has been a clinical impression that even though the bypass operation is not successful in restoring blood flow, there are no deleterious effects, since collateral vessels have been undisturbed.[4] However, in several cases studied plethysmographically a definite decrease in digital blood flow has been observed when operation is unsuccessful, suggesting that collateral flow is in fact reduced.

The studies made during operation are of particular interest. The importance of the hypogastric, inferior mesenteric, and lumbar arteries as collateral pathways in patients with occlusive aortic disease has long been recognized and is strikingly demonstrated in these studies. In Case 1 (complete occlusion at the aortic bifurcation) application of the occluding clamp to the aorta produced only a moderate reduction in peripheral blood flow (Fig. 2). However, resection of the aortic bifurcation with division of the in-

ferior mesenteric and several lumbar arteries reduced peripheral blood flow to zero. Restoration of flow through the aorta and right iliac artery produced an increase inflow in the left second toe, indicating the important role the internal iliac arteries play in maintaining peripheral blood flow in patients with aortic occlusive disease. Because of the importance of these vessels, caution must be used in performing aortic resection when there is extension of the occlusive process distally to such a degree that restoration of circulation is jeopardized. Under these circumstances it is best to employ a bypass procedure, thus leaving these collateral vessels undisturbed.

The differences noted in digital blood flow during operation in Case 5 (abdominal aortic aneurysm) are evidence of the lack of development of collateral arterial pathways frequently observed with this lesion (Fig. 9). One of the most interesting observations was made in Case 5 at the end of operation, when it was noted that digital blood flow had increased threefold over the values obtained after induction of anesthesia. The fact that the high volume flow lasted only a short time suggests that it represents reactive hyperemia resulting from prolonged aortic occlusion.[8]

It must be emphasized again that these random observations have little significance at this time because of their small number and the limiting factors described above. The plethysmographic method of measuring peripheral blood flow may find some clinical application in evaluation of patients with occlusive aortic and arterial disease beyond that afforded by careful clinical examination. However, studies of this type are primarily designed to increase our understanding of the compensatory changes associated with occlusive arterial disease and pattern of response to surgical restoration of normal aortic and peripheral arterial lumina.

Summary

Digital plethysmography was performed on 25 patients with arteriosclerotic occlusive disease or aneurysm of the aorta and peripheral arteries. From nine of these cases the results of digital blood flow studies before and at intervals after operation were selected to illustrate certain aspects of the study.

In three cases of aortic occlusion digital blood flow in the lower extremities was only slightly increased early after luminal restoration. Later, however, blood flow reached near normal levels. The cause for this gradual rather than a prompt increase in digital blood flow is not clear, but may be due to gradual reduction in volume of the "arterial reservoir" or to a reduction in blood pressure secondary to a decrease of peripheral resistance.

The increase in lower digital blood flow following resection and homograft replacement of an abdominal aneurysm reflects the effect on peripheral blood flow of luminal distortion produced by the aneurysmal process.

Plethysmographic studies during operation demonstrated the differences in collateral circulation of patients with complete aortic occlusion and those with aneurysms. In addition the phenomenon of reactive hyperemia following restoration of blood flow after temporary aortic occlusion was observed.

Alterations in lower digital blood flow following successful and unsuccessful bypass operations for femoral artery occlusion were described. It appears that the bypass procedure, when unsuccessful, may significantly reduce peripheral blood flow.

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DISCUSSION

DR. EDWARD A. EDWARDS, Boston: We have used ergometry to determine the effect of operation on muscle function of the limb. In our apparatus the calf muscles are stimulated electrically by the rhythmic impulses of the Batrow stimulator, with the foot acting against a load and with registration of the resultant movement.

The slide shows the results in a patient in whom peripheral pulses were restored by the insertion of an aortic bifurcation graft. The preoperative contractions show an abnormally low amplitude, and a certain abnormality of configuration. The load was only 5 lb. A normal limb would be able

to lift 15 or 20 lb., with contractions of much greater magnitude.

Surprisingly, the contractions produced two and one-half months after operation are even smaller, although the pedal pulses are excellent, in spite of the patient's assertion of effective walking ability. It is finally in the curves made six months postoperatively that we see a return to apparently normal function.

This delay in return of muscle function after successful arterial reconstruction is usual.

Only about one-third of patients who have had lumbar sympathectomy show a certain increase in muscle power; the improvement is slower and of smaller degree than after reconstruction.

DR. DAVID I. ABRAMSON, Chicago: I think that it is necessary to point out that the blood flow data obtained by the methods described represent the responses of a very specialized vascular bed. I don't feel that it necessarily follows that the changes observed with digital plethysmography would be duplicated if another vascular bed, such as the muscles in the leg, was examined.

I feel that ultimately it will be necessary to evaluate all these procedures not under resting conditions but by placing a load on the muscles, as, for example, with exercise. Furthermore, the blood flow studies will have to be performed not on the digits, where the blood vessels are markedly under the control of the vasomotor center, but on the forearm and the leg, which contain vascular beds which are more representative of vascular responses in other parts of the body.

DR. CREECH, I want to thank the discussers for their remarks. The technical aspects of reconstructive surgery of the aorta and major peripheral vessels are now well established, and I think we should turn our attention to some of the physiologic changes that occur as a result of the disease and its surgical correction. The plethysmographic method is not an entirely satisfactory means of investigating peripheral blood flow; however, with experience, a great deal of useful data can be derived by this means. It is apparent that many patients will have to be studied in this way before the results can be properly interpreted.

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Collateral Circulation in Health and Disease

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Los Angeles

The present studies were carried out because of a need for a better understanding of the functional capacity of the collateral circulation in health and in disease. Aortography has been an important method of obtaining anatomic evidence of the collateral circulation [1]; however, little attention has been paid to its functional effects. As the presence of collateral circulation is at times highly important and may be the only circulation sustaining a limb, it would be desirable, if possible, to measure the degree of collateral circulation to a limb. The present studies were carried out to determine (1) if measurements of the circulation through major and collateral channels could be made and (2) differences in the amount of collateral circulation in normal subjects and in patients with arteriosclerosis obliterans.

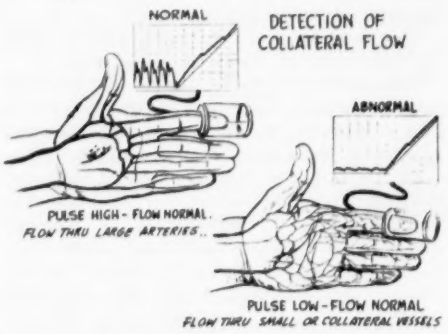

Fig. 1.—The collateral circulation index in health and in disease. Small pulse waves and a large blood flow indicate flow through small or collateral channels.

Methods and Materials

Two plethysmographic methods were employed: I. The first compared the volume (height) of the pulsation of a digit with the volume rate of blood flow in a digit (Fig. 1).[2] An electronic plethysmograph was employed.[6] A small plastic cup of 14 cc. volume was placed on the digit, and the height of the pulsations was recorded in terms of cubic millimeters of volume displacement per pulse beat. In all cases, the volume of the digit in the cup was 4 cc. The volume rate of blood flow was measured employing the venous occlusion technique with the venous occluding cuff placed at the ankle or wrist.[2] The cuff was inflated quickly to above venous pressure, producing swelling of the digit, and as a result the base line of the plethysmogram rose. The rate of rise was an indication of the rate of blood flow through the digit and was measured in terms of cubic millimeters per second. From the figures obtained in these two ways (height of pulsation and relative blood flow) a collateral circulation index was calculated:

$$\text{Collateral Circulation Index} = \frac{\text{relative volume rate of flow of the digit in cu. mm. per second}}{\text{volume pulsations of the digit in cu. mm.}}$$

II. The second method was based on the measurement of blood pressure at the periphery before and after compression of arteries. The method for recording systolic blood pressure has been described in detail elsewhere [4] and is as follows: A blood pressure cuff is placed around the limb where the systolic blood pressure is to be measured (at the ankle, Fig. 2), and a plethysmographic cup is sealed on the toe in order to record pulsations. The cuff is inflated rapidly to above arterial pressure, at which time the pulsations at the toe cease. The cuff is then deflated slowly until the toe swells which is signaled on the plethysmogram by an abrupt rise of the stylus of the plethysmograph. This is the point at which arterial blood first passes

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From the Heart Research Foundation and Foundation for Surgical Research, Hospital of the Good Samaritan, and the Departments of Medicine and Surgery, University of Southern California Medical School.

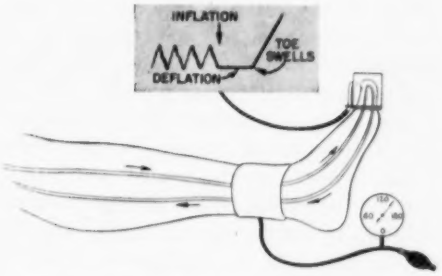

Fig. 2.—Technique of measuring systolic blood pressures at the ankle. The occluding cuff is inflated until it obliterates the pulse at the toe. The cuff pressure is then decreased until the toe swells abruptly. At this point the stylus of the plethysmograph rises sharply and the gauge indicates the systolic blood pressure.

under the cuff and enters the toe. At the beginning of the swelling the pressure in the gauge is noted, which is the systolic blood pressure for the part. Pressures below 20 mm. Hg were not measurable by this technique. In order to determine if blood is traveling through primary or collateral channels, measurements of pressure were made before and after manual compression of certain arteries. The arteries compressed were the femoral, popliteal, dorsalis pedis, and posterior tibial, and the upper brachial, lower brachial, radial, and ulnar.

Results

I. The collateral circulation index was studied in 15 normal subjects and 20 patients with moderate arteriosclerosis obliterans (Fig. 3). The average index for the normal subjects was 3.0 as compared with 7.0 in patients with arteriosclerosis obliterans. After a posterior tibial nerve block, the average for the diseased group was 30.0. After a lumbar sympathectomy (L-2, L-3 removed), it was 24.0 (range 14.0 to 32.0). These studies indicate that in patients with arteriosclerosis obliterans, especially after a posterior tibial nerve block or sympathectomy, the blood flow is relatively greater than is the height of the pulsation as compared with normal subjects. The effect of an obstruction of the iliac artery on the index is illustrated by a patient, 45 years old, with complete obstruction of the artery. Before thromboendarterectomy the height of the pulsations at the toe was 1.0 cu. mm., the blood flow was 8.0 cu. mm. per second,

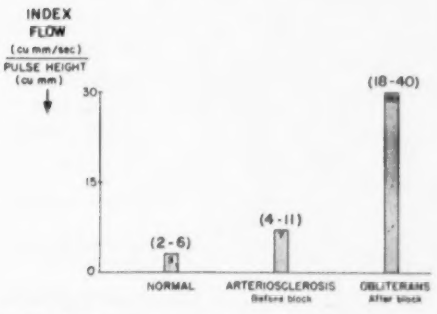

Fig. 3.—The collateral circulation index in health and disease. The index suggests that the flow through collateral or small vessels is greater in arteriosclerosis obliterans and after a block than in normal subjects.

Fig. 4.—Collateral circulation around an obstruction in the femoral artery.

and the index was 8.0. After a successful thromboendarterectomy the height of the pulsation was 6.0, the blood flow was 8.0, and the index was 1.3.

II. Systolic blood pressures at the foot were measured before and after arterial compression in normal subjects and in patients with moderate arteriosclerosis obliterans.

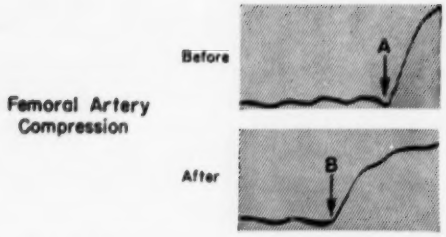

Fig. 5.—Measurement of blood pressure made from the right foot in a patient with an occlusion of the femoral artery. *A*, systolic blood pressure read from gauge at rise of base line before manual compression. *B*, systolic blood pressure read from gauge at rise of base line after manual compression of artery.

Femoral Artery.—The first patient studied (Table 1, Case 2) had an arteriosclerotic segmental occlusion of the right femoral artery located between the inguinal ligament and the profunda femoris (Fig. 4). The blood pressure at the foot measured 100 mm. of mercury before and after manual compression of the femoral artery. Figure 5, *A* and *B*, shows the abrupt rise of the plethysmographic stylus at 100 mm. of mercury cuff pressure before and after compression of the artery. These findings indicate that the entire flow to the foot was through collateral channels and that no blood was passing through the common femoral artery. This was confirmed at surgery. The collateral pathways in this case probably were as follows (Fig. 6): through the (1) superior and inferior gluteal branches of the hypogastric arteries to the medial and lateral femoral circumflex to the first perforating branches of the profunda femoris; (2) obturator branch of the hypogastric artery to the medial femoral circumflex branch of the profunda femoris; (3) internal pudendal branch of the hypogastric artery, to the medial femoral circumflex artery; (4) deep iliac circumflex branch of the external iliac to the lateral femoral circumflex branches of the profunda femoris; (5) inferior gluteal branch of the hypogastric artery to the perforating branches of the profunda femoris. For purposes of comparison the collateral circulation was studied in a normal subject before and after manual compression of the common femoral artery (Table 1, Case 1). The site of compression is shown in Figure 6, *A*, and the plethysmographic trace shown in Figure 7. Before compression the pressure was 140 mm. Hg and after it was not measurable. This indi-

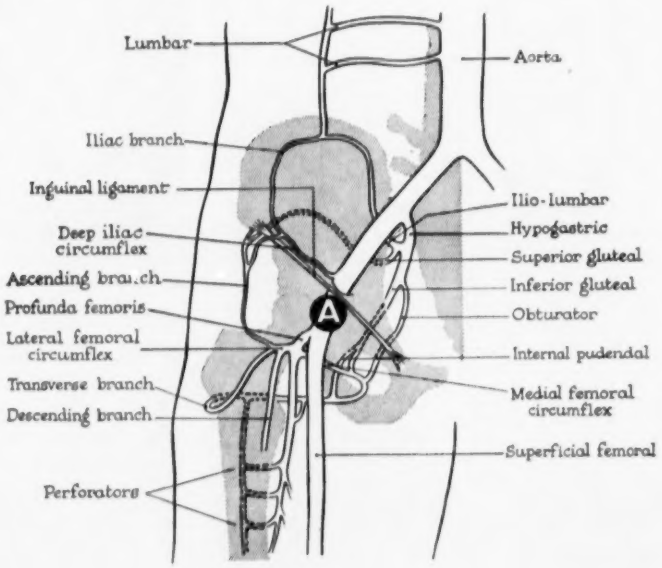

Fig. 6.—Collateral channels around the hip when the femoral artery is obstructed at *A*.

Table 1

Type of Case	BLOOD PRESSURE AT FOOT WHEN ARTERY COMPRESSED MANUALLY						Route of Collateral Flow
	None	Femoral Artery	Popliteal Artery	Upper Tibial Artery	Post. Tib. Artery	Post. Tib. & Dors. Pedis	
#1 Normal	140	0	0	121	110	0	Not measurable
#2 Occ. femoral artery	100	100	0	80	70	0	Hip collateral
#3 Occ. popliteal artery	100	0	90	70	60	0	Knee collateral
#4 Occ. post. tib. artery	100	0	0	0	60	0	Dorsalis pedis collateral
#5 Occ. dors. ped. artery	100	0	0	60	0	0	Post. tib. collateral
#6 Occ. post. tib. & dors. ped.	100	0	0	0	0	0	Not measurable

0 = Pressure not measurable

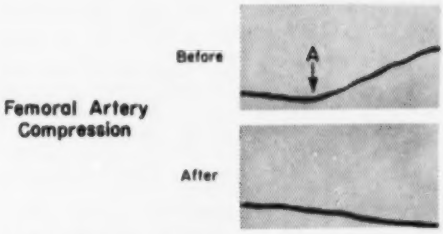

Fig. 7.—Systolic blood pressure in a normal subject before and after compression of the femoral artery. Before, the pressure at the toe was 140 mm. of mercury. After, it was not measurable.

cated that the significant flow was through the common femoral artery and not through the collateral vessels. Similar studies were carried out in 20 normal subjects and similar results were obtained.

Popliteal Artery.—Measurements in 20 normal subjects after compression of the popliteal artery revealed the absence of a measurable pressure at the foot (Fig. 8, *B*). One of these subjects is shown in Table 1, Case 1. In a patient with a thrombosed aneurysm of the popliteal artery (Table 1, Case 3), the pressure at the foot after compression of this artery fell only slightly. This indicated that blood was flowing through collateral channels as well as through the popliteal artery. The probable collateral pathways are shown in Figure 8 and are from the (1) femoral artery through the descending branch of the lateral femoral circumflex to the lateral superior genicular and anastomotic branches to the lateral inferior genicular arteries; (2) highest genicular arteries to the medial inferior genicular arteries; (3) highest genicular arteries through musculoarticular branches to the anterior tibial recurrent artery to the anterior tibia; (4) superior to the inferior

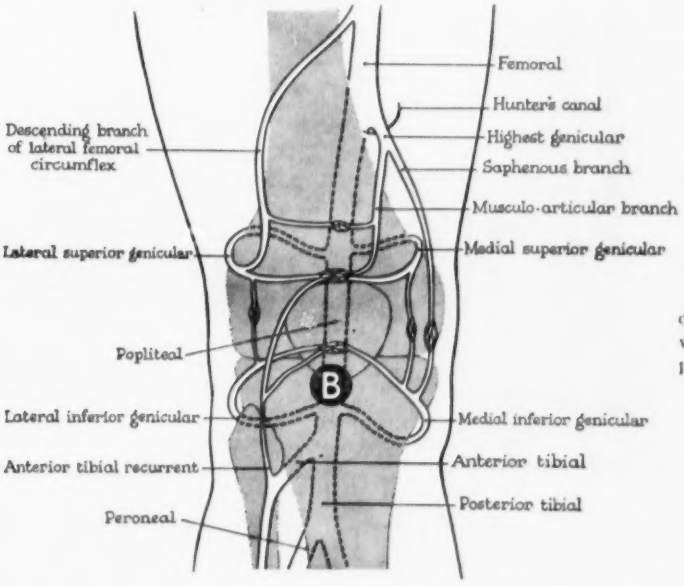

Fig. 8.—Collateral circulation around the knee when an obstruction is present at *B*.

genicular arteries through anastomotic branches.

Posterior Tibial and Dorsalis Pedis Arteries.—The average pressure in the posterior tibial artery in 20 subjects was 11 mm. of mercury higher than that in the dorsalis pedis. In a normal subject (Table 1, Case 1) manual compression of the posterior tibial artery at site *C* in Figure 9, gave a pressure of 110 mm. of mercury compared with a pressure of 121 mm. of mercury when the dorsalis pedis was compressed (Fig. 9, *D*). In one patient with arteriosclerosis obliterans an occlusion already existed in the posterior tibial artery and manual compression over this artery failed to alter the pressure at the foot (Table 1, Case 4). Manual compression of the dorsalis pedis caused the pressure to fall too low to be measured (Table 1, Case 4). In this case the collateral circulation was mainly through the dorsalis pedis artery. In a patient with arteriosclerosis obliterans with occlusion of the dorsalis pedis artery (Table 1, Case 5), compression of this artery at point *D*, Figure 9, caused no change in the pressure at the foot. However, compression of the posterior tibial artery in this patient caused the pressure to fall to an immeasurable level. In this case the major circulation to the foot was mainly through the posterior tibial artery. In 20 normal subjects, when both the dorsalis pedis and posterior tibial arteries were compressed manually at points *D* and *C* of Figure 9, there was no measurable pressure at the foot. Thus, the peroneal artery did not supply a significant circulation to the foot. This same finding was observed in one patient with occlusion of these two arteries due to arteriosclerosis

Table 2

Type of Case	Blood Pressure at Ankle when Artery Compressed Manually						Route of Collateral Flow
	None	Brachial Artery High	Brachial Artery Low	Ulnar Artery	Radial Artery	Ulnar & Radial Arteries	
1. Normal	117	0	0	110	110	0	Not measurable
2. Occlusion brachial artery—high	98	70	0	90	90	0	Shoulder collateral
3. Occlusion brachial artery—low	70	0	70	60	60	0	Elbow collateral
4. Occlusion ulnar artery	70	0	0	60	0	0	Radial artery collateral
5. Occlusion radial artery	70	0	0	0	60	0	Ulnar artery collateral
6. Occlusion radial & ulnar arteries	70	0	0	0	0	0	Not measurable

0 = Pressure not measurable

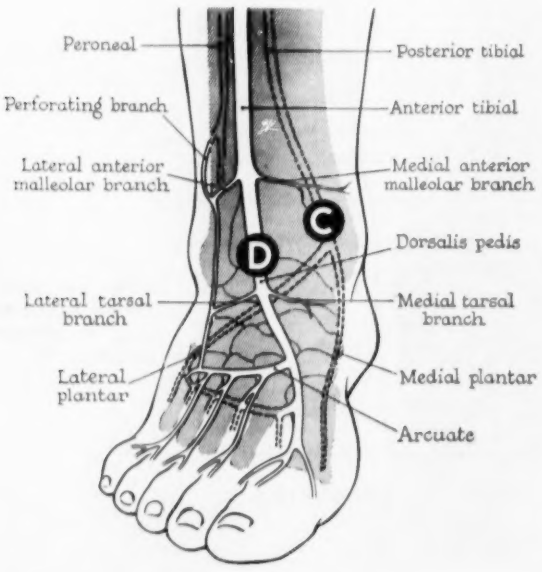

Fig. 9.—Collateral circulation in the foot when an obstruction is present at *C* or *D*.

obliterans (Table 1, Case 6). Amputation was performed shortly after the studies were made.

High Brachial Artery.—Normally (20 subjects) compression of the brachial artery, high near the axilla, resulted in no measurable pressure at the finger (Fig. 10). This is illustrated in a normal subject (Table 2, Case 7). The collateral flow in a patient with arteriosclerosis obliterans with an obstruction high in the brachial artery is shown in Table 2, Case 8. The blood pressure at the finger did not change after compression above the profunda brachii, which indicates that the collateral channels were of functional significance. The route of collateral circulation probably was from the (1) transverse scapular to the thoracoacro-

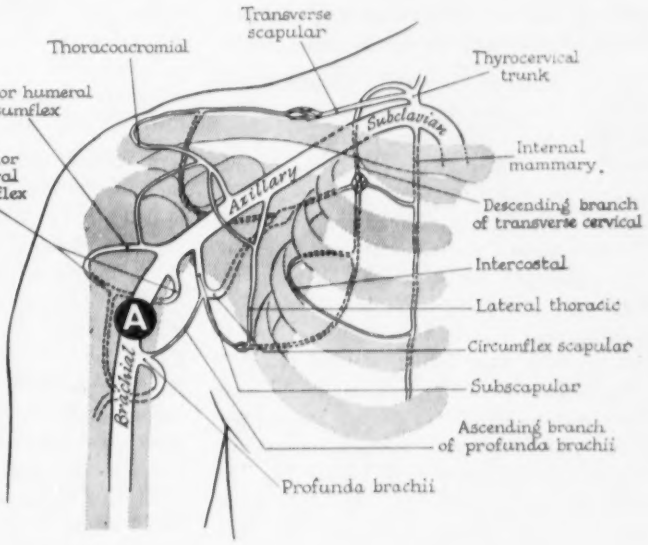

Fig. 10.—Collateral circulation around the shoulder when obstruction is present at *A*.

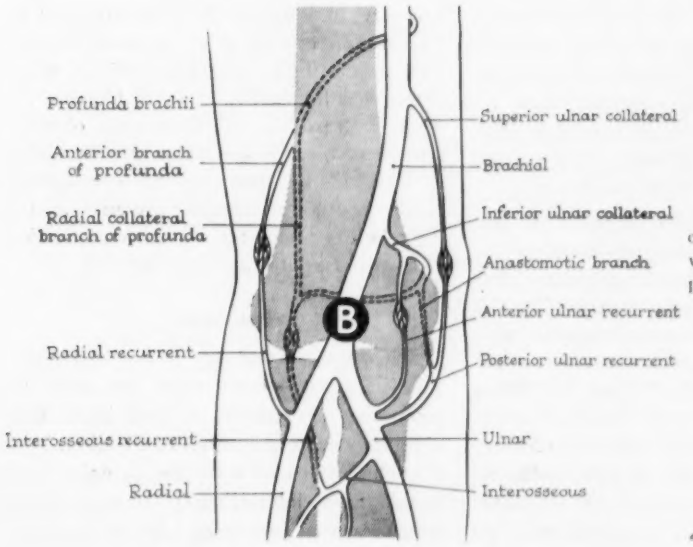

Fig. 11.—Collateral circulation around the elbow when an obstruction is present at *B*.

mial to the circumflex humoral to the deep brachial artery; (2) transverse scapular to the thoracoacromial to the lateral thoracic to the ascending branch of the profunda brachii to the deep brachial; (3) internal mammary to the intercostal to the circumflex scapular through the ascending branch of the deep brachial to the deep brachial; (4) descending branch of the transverse cervical through the circumflex scapular through the ascending branch of the profunda brachii to the profunda brachii.

Low Brachial Artery.—Normally (20 subjects), manual compression low in the brachial artery showed no measurable pressure at the finger (Fig. 11). One normal subject is shown in Table 2, Case 7. The results indicate that normally the collateral channels around the elbow are not functionally significant for supplying blood to the digit. In one patient (Table 2, Case 9) with arterial disease with occlusion low in the brachial artery the collateral channels were of functional significance. In this case there was no significant change in the pressure at the finger after manual compression of the brachial artery at *B*, Figure 11. The pathways for the collateral circulation probably were as follows: from the (1) profunda brachii through the radial recurrent to the radial; (2) profunda brachii through the radial collateral branch of the profunda to the interosseous recurrent; (3) superior ulnar collateral to the posterior ulnar recurrent to the ulnar, and (4) inferior ulnar collateral to the anterior ulnar recurrent and anastomotic branches to the ulnar.

Radial and Ulnar Arteries.—In 20 normal persons compression of the ulnar artery gave somewhat higher pressures than compression of the radial artery (Fig. 12, *C* and *D*). The difference averaged 12 mm. mercury. An example of one normal subject is shown in (Table 2, Case 7). When both of these arteries were occluded simultaneously there was no measurable pressure at the digit; thus the smaller collateral vessels which were present were not functionally significant. In a patient with arteriosclerosis obliterans with obstruction of the ulnar artery, compression of this artery at *D* (Fig. 12) did not alter the pressure at the digit (Table 2, Case 10); however, manual compression of the radial artery at *C* (Fig. 12) caused the pressure to drop to 0, indicating that the small collateral channels, that is the interosseous and the branches of the radial and ulnar arteries, were not carrying a significant amount of collateral circulation. Likewise, in a patient with arteriosclerotic obliterative disease who had an obstructed radial artery, compression of the radial artery at *C*, Figure 12, did not alter the pressure at the digit (Table 2, Case 11); however, pressure on the ulnar artery at *D*, Figure 12, resulted in no measurable pressure at the digit, indicating that the ulnar artery was the major supply of blood to the digit. In a patient with disease and obstruction of both radial and ulnar arteries, Table 2, Case 12, as shown by an arteriogram, there was no measurable pressure at the digit before and after manual compression of the arteries at *C* and *D*, Figure 12.

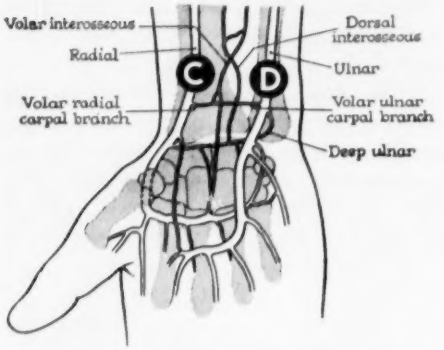

Fig. 12.—Collateral circulation in the hand when an obstruction is present at *C* or *D*.

Comment

The measurement of collateral circulation in small vessels could be made by comparing the relative rate of blood flow with the volume pulsations of the digit. This procedure is based upon the principle that blood flows intermittently through large patent arteries, producing high pulse waves,

and less intermittently through small or partially obstructed arteries, producing low pulse waves. The volume flow per second may be the same in these two cases. From these data (pulse height and flow rate) the collateral circulation index was calculated. Studies showed that patients with arteriosclerosis obliterans have relatively low pulsations compared with the volume rate of flow (high index). A high index was obtained also in patients with moderate arteriosclerosis obliterans after a posterior tibial nerve block or after a lumbar sympathectomy. These findings suggest that a sympathectomy dilates small vessels and allows an increased volume rate of blood flow without producing a significant increase in the pulsation of the digit. The importance of the index in identifying the type of flow to a digit was clearly illustrated in one patient. Before a thromboendarterectomy of the iliac artery, the collateral circulation index was high because a significant amount of blood was flowing through small or collateral channels. After surgery the index fell, indicating that the major channel had been cleared.

Studies of the systolic blood pressure at the finger or foot before and after manual compression of arteries made it possible to determine the functional significance of the collateral circulation. In normal subjects there was no significant collateral circulation about the hip when the femoral artery was compressed. Similarly, there was no significant collateral circulation about the knee when the popliteal artery was compressed. In normal subjects when the dorsalis pedis artery was compressed the circulation at the foot was well maintained through the posterior tibial artery. When the posterior tibial artery was compressed the circulation through the dorsalis pedis artery was significant. When both of these arteries were compressed, there was no measurable pressure which means that the collateral vessels (i. e., the peroneal and others) were not of functional significance. Normally the posterior tibial artery carried a slightly higher pressure than did the dorsalis pedis and was of greater importance than the dorsalis pedis artery in supplying circulation to the foot. In normal subjects after compression of the upper brachial artery above the profunda brachii there was no measurable collateral circulation around the shoulder. Normally compression of the brachial artery at its lower portion resulted in no measurable collateral circulation about the elbow. Normally compression of the ulnar artery produced only slight alterations in the pressure at the finger, and compression of the radial artery had a similar result. The pressure in the radial artery generally was higher than that in the ulnar artery. Normally when the radial and ulnar arteries were compressed simultaneously there was no significant collateral circulation to the digit. In the presence of chronic obstructive arterial disease, however, the collateral circulation often was of functional importance. With chronic obstruction to the femoral, popliteal, high and low brachial arteries, a significant collateral circulation was measured. The amount of collateral circulation, of course, will not be the same in all patients, since it is dependent upon such factors as the systemic blood pressure, the speed of occlusion of the vessels, and the presence or absence of potential collateral circulation.[5-7]

Conclusions

The presence and amount of collateral circulation could be estimated by two techniques: (1) by calculating the collateral circulation index and (2) by measuring the blood pressure at the periphery before and after manual compression of certain arteries. A posterior tibial nerve block or sympathectomy increased the flow through collateral channels. In normal subjects there was little collateral circulation around the shoulder, elbow, hip, and knee. With chronic obstructive arteriosclerotic occlusive disease of certain large vessels the collateral circulation was measurable and was functionally significant.

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DISCUSSION

Dr. Frank H. Leeds, San Francisco: For some time we have been very interested in measuring the collateral circulation and the effect of pressure in the small blood vessels following reconstructive surgery. In 500 patients, 102 of whom were subjected to sympathectomies, we studied blood flows and performed tests aimed at the measurement of actual pressure in the small blood vessels. We found it very difficult to quantitate the blood flow measurement but found that the measurement of actual pressure in the small blood vessels, as reflected by the reactive hyperemia test with elevation of the feet, has been a very useful test.

[Slide] This test consists briefly of elevating the feet to 65 cm. above the heart level and gradually dropping them. The circulation is then occluded by inflating cuffs on the extremities. When the cuff is deflated in a normal case there is immediate return of blood flow in the foot even when elevated 65 centimeters above heart level.

In this patient you notice a return of blood flow in the right foot when at a level of 45 cm., and the complete return of blood flow when dropped to a level of 15 cm.

[Slide] We checked our observations also by plethysmography in order to measure blood flow at levels indicated by the reactive hyperemia test. Here you can see that the level is zero before sympathectomy, but subsequently elevation of the limb can gradually be increased with the development of collateral circulation.

In summary, we feel that you can use this test by which one can actually measure the effective arterial pressure in small blood vessels. We believe it correlates a little better with actual functional results over long term follow-up periods.

Dr. Travis Winsor, Los Angeles: I would like to emphasize that the technique for measuring the blood pressure at the angle before and after occlusion of the femoral artery manually is not dependent on small blood vessel flow, as Dr. Abramson suggested. Measurements of the amount of collateral circulation before surgery have been of value in deciding whether or not an effort should be made to preserve the collateral circulation or if the collateral circulation could be severed without detrimental effect. Measurements made postoperatively enable the surgeon to determine if blood is flowing through the major channels or through collateral vessels.

Dr. Howard Payne, Los Angeles: I wish to thank the discussants for their fine and kind discussion of our presentation this morning. These plethysmographic studies we have shown are of tremendous value to the surgeon in the diagnosis and evaluation of his patient before surgery. Postoperative observations can be accurately made without resorting to arteriograms.

We feel it is important to know the functional capacity of the collateral blood flow to a diseased extremity. As this may be the only significant blood flow to the part, therapy can be planned or altered depending upon the presence or absence of collateral flow.

As you have seen, it is possible to demonstrate the presence and the functional capacity of collateral blood flow by using the plethysmographic technique.

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The Importance of Angiocardiography for Visualizing the Thoracic Aorta

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Angiocardiography, the intravenous method of visualizing the cardiovascular system, has been available since 1938.[1,2] Strict adherence to the details of the method regularly results in opacification of the thoracic aorta.[3] Aortography by left auricular,[4] left ventricular,[5-8] and aortic puncture and catheterization[9,10] are technically more difficult and carry a greater risk and should not be used routinely. The purpose of this paper is to reiterate the practicality of angiocardiography for aortic visualization, to demonstrate how simply mediastinal tumors may be differentiated from aortic aneurysms, and to illustrate the importance of visualizing the aorta. Discovery of aortic disease is no longer of academic interest, the latest surgical triumph being resection of aortic aneurysms and replacement by grafts.

Technique of Angiocardiography

Angiocardiography is a roentgen method of visualizing the cardiovascular structures. It is accomplished by making a rapid injection (one and one-half seconds) of a concentrated organic iodide solution into the arm vein. Speed of injection is essential and is achieved by the use of a special needle-stopcock unit of 12 gauge and a special 50 cc. Luer-Lok syringe with 12 gauge tip and by injection of the contrast substance during inspiration with the arm elevated. Sodium acetrizoate (Urokon sodium), 70%, has been found to be a contrast medium with few side-effects and reactions.[11] The dose of sodium acetrizoate for children is 1 cc. per kilogram of body weight; for adults, depending on weight, it is between 35 and 50 cc.

For angiocardiography of the aorta in the adult, full size 14×17 in. films may be necessary. In such cases, a standard stereocassette shifter may be used and will provide two films per injection. The circulation time is usually normal unless there is heart failure. Accordingly, exposures at seven and nine seconds after the beginning of the injection will, in the majority of instances, allow study of the thoracic aorta. For children and adults of small stature, the Fairchild 9×9 in. roll film cassette,[12] or the new 12×12 in. F-X-R magazine[13] will provide multiple (two to three per second) films during opacification of the cardiovascular system.

The erect left anterior oblique view is the best position for visualizing the aorta and brachiocephalic vessels. There should be no hesitation to give a second injection to secure lateral or frontal views. Death has rarely occurred during angiocardiography for the study of the thoracic aorta.

Differentiation of Mediastinal Tumor and Aneurysm

The thoracic aorta, save for its root, which lies deep within the substance of the heart, is ordinarily readily discernible on roentgenography. When disease of the mediastinal structures (especially tumor) occurs, it is difficult, if not impossible, to distinguish it from the adjacent cardiovascular structures. In such instances, angiocardiography is essential, and by visualizing the cardiac chambers and great vessels, it will readily make the differential diagnosis possible.[1-3]

Figure 1*A* is an example of a large mediastinal mass which was adjacent to and could not be separated from the ascending aorta. Visualizing the thoracic aorta (Fig. 1*B*) readily established the extravascular nature of the mass and excluded the diag-

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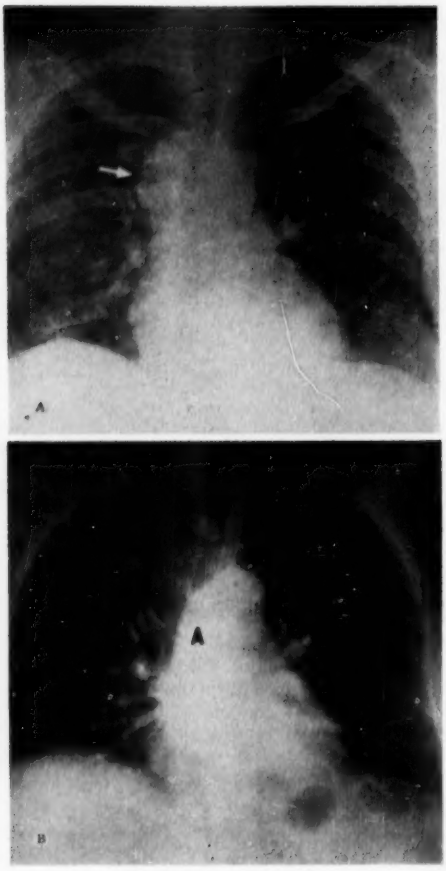


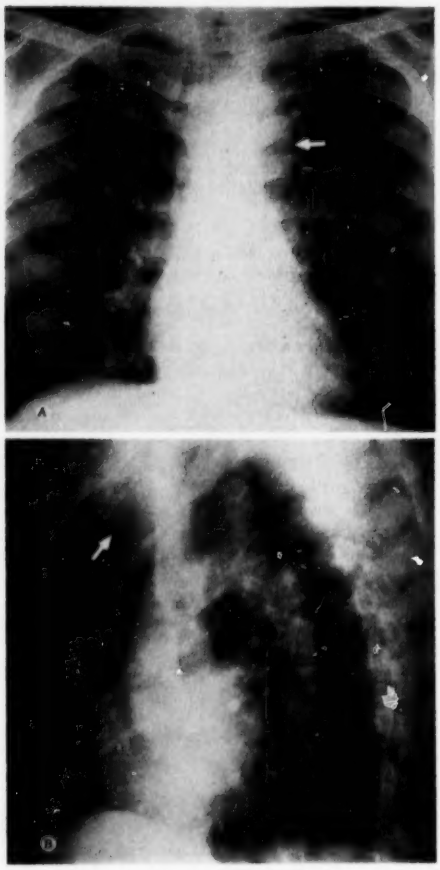
Fig. 1.—Pericardial cyst simulating aneurysm of the ascending aorta, in a 58-year-old woman. *A*, conventional frontal x-ray reveals a mass (arrow) which cannot be differentiated from the ascending aorta. *B*, frontal angiocardiogram shows the intact normal ascending aorta (A) excluding aneurysm. At operation a pericardial cyst attached to the pericardium by a diverticulum was found.

nosis of an aortic aneurysm. Another patient (Fig. 2*A*) had a tumor which surrounded and obscured the aortic arch. Visualizing the normal aorta and its brachiocephalic vessels (Fig. 2*B*) excluded aortic aneurysm and established the presence of a mediastinal tumor.

Acquired Disease of the Aorta

Syphilitic Aneurysms.—In recent years, the incidence of cardiovascular syphilis and aortic aneurysms has decreased.[14] Improvement in surgical techniques has made possible excision of saccular aneurysms and suture of the aorta,[16] as well as resection and replacement of the aneurysm by grafts.[17] It has become important, therefore, to clearly establish the diagnosis by visualizing the aneurysm and demonstrating the degree and nature of involvement of neighboring structures. This can be easily accomplished by angiocardiography, without resort to aortic puncture or retrograde aortography.

Fig. 2.—Dermoid cyst simulating aortic aneurysm, in a 51-year-old man. *A*, a pulsatile rounded left anterior mass (arrow) surrounds the aortic arch. *B*, left anterior oblique angiocardiogram shows a normal thoracic aorta. Arrow points to the nonopacified anterior superior mass, which on excision proved to be a dermoid cyst.



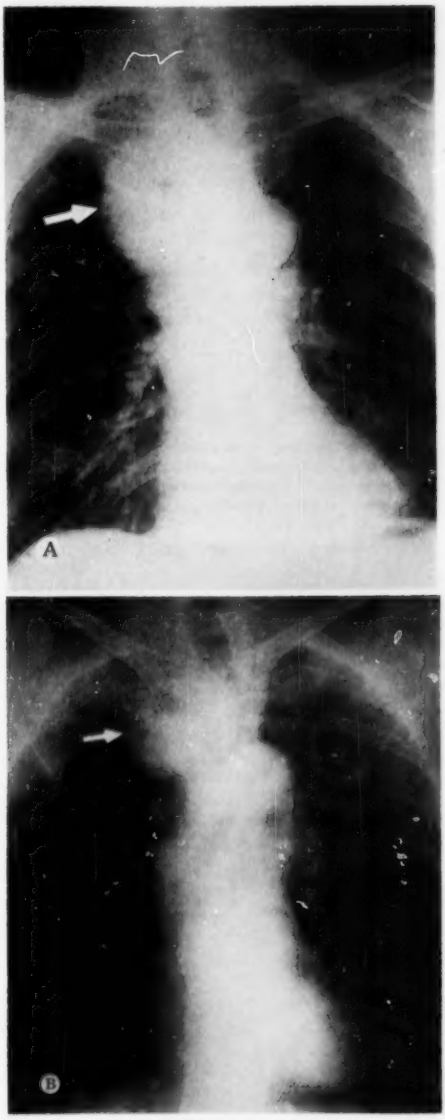


Fig. 3.—Syphilitic aneurysm of innominate artery, in a 53-year-old man. *A*, a huge nonpulsatile mass (arrow), indistinguishable from the ascending aorta, is markedly displacing and narrowing the trachea. *B*, frontal angiocardiogram discloses a saccular aneurysm of the innominate artery, lined with thrombus (arrow). Excision of aneurysm and replacement by homograft resulted in relief of dyspnea. There is a four-year follow-up.

Figure 3*A* reveals a huge superior mediastinal mass which markedly deviates and narrows the trachea. Opacification of the left cardiac chambers and aorta (Fig. 3*B*) demonstrated a saccular aneurysm of the innominate artery. Subsequently, resection of the aneurysm and replacement with a homograft afforded complete relief of tracheal obstruction; the patient has been well for more than four years.

Arteriosclerosis of the Thoracic Aorta.—Arteriosclerosis of the thoracic aorta is becoming commoner because of increasing longevity. Dilatation, elongation, tortuosity, and buckling of the thoracic aorta occur commonly with arteriosclerosis and may simulate aneurysms. Heretofore, discovery of aortic aneurysms was mostly of academic interest; wiring and cellopane wrapping having been of limited success. Newer surgical techniques, especially excision of the aneurysm and replacement with homologous aortic grafts, promise to be a more effective treatment.[17]

The eary diagnosis of thoracic aortic aneurysm is important; duration of life, once symptoms begin, is apparently limited.[18,19] Roentgenography, fortunately, provides a significant clue by disclosing abnormal mediastinal or hilar shadows. If the vascular nature of the lesion is obscure, contrast visualization of the thoracic aorta by the method of angiocardiography will establish the diagnosis.

Figure 4*A* reveals a saccular aneurysm of the descending arch of the thoracic aorta in a 65-year-old woman with hypertension who had hemoptysis. The angiocardiogram (Fig. 4*B*) taken earlier revealed constriction of the left pulmonary artery by the aneurysm. Figure 5*A* is the frontal angiocardiogram of a 57-year-old man who had backache due to erosion of the thoracic spine by a fusiform arteriosclerotic aneurysm of the descending aorta. The smooth uncalcified character of the ascending and transverse portions of the aorta (Fig. 5*B*) was evidence in favor of the arteriosclerotic and against a syphilitic etiology of the aneurysm.

Dissecting Aneurysms.—Dissecting aneurysms of the aorta are really ruptures of the inner and medial coats of the aorta with dissection. Usually they begin with intimal

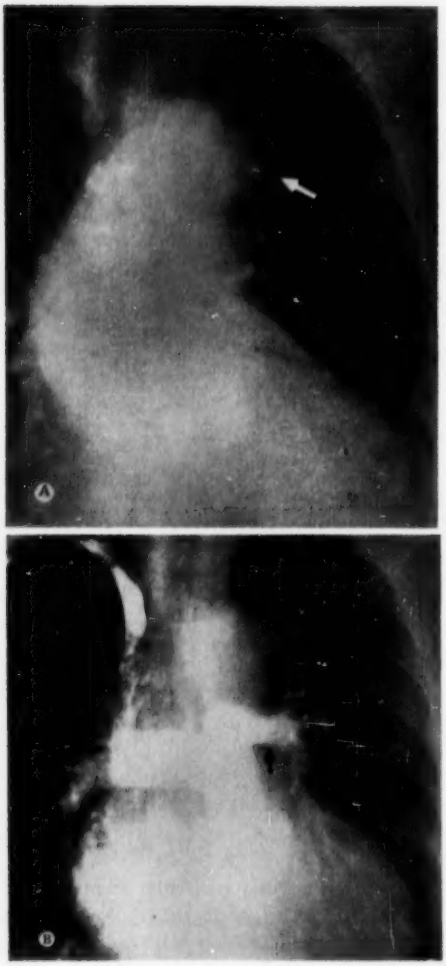


Fig. 4.—Saccular arteriosclerotic aneurysm of aortic arch causing hemoptysis, in a 65-year-old woman. *A*, frontal angiocardiogram shows saccular aneurysm surrounded by thrombus (arrow) in the descending portion of the aortic arch. *B*, earlier angiocardiogram (four seconds) shows stenosis of the left pulmonary artery (arrow) by the aortic aneurysm.

rupture of an atheromatous plaque or ulcer or follow medial cystic necrosis. The blood then splits or dissects within the medial layer, separating it into an inner and outer wall. The ascending aorta is a common and often fatal site of rupture. Another, and apparently not as lethal, is at the origin of the left subclavian artery. A hypertensive patient had sudden thoracic pain, had normal electrocardiographic studies, and developed a huge widened mediastinal shadow. Angiocardiography (Fig. 6) showed abrupt narrowing of the descending aorta, just beyond the left subclavian artery, due to massive adjacent hematoma, establishing the diagnosis of dissecting aneurysm of the aorta.

Buckling of the Brachiocephalic Arteries.—Buckling of the brachiocephalic arteries may simulate mediastinal tumors.[20] Usually there is hypertension, and pulsations may

Fig. 5.—Fusiform arteriosclerotic aneurysm of the descending aorta eroding the spine, in a 57-year-old man. *A*, frontal angiocardiogram reveals aneurysm (arrow) lined with thrombus. *B*, left anterior oblique view, showing the aneurysm against the spine (arrow). Note the normal appearance of the ascending and transverse aorta. Resection and replacement of aneurysm by homograft was followed by clotting of an unsuspected abdominal aortic aneurysm.

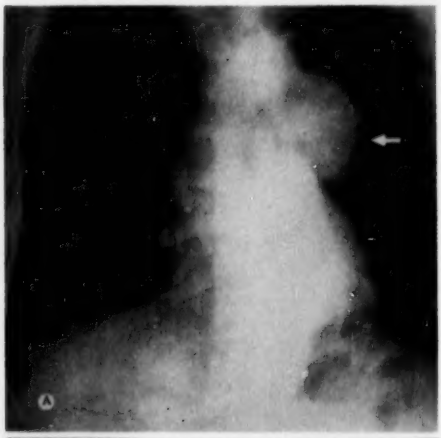


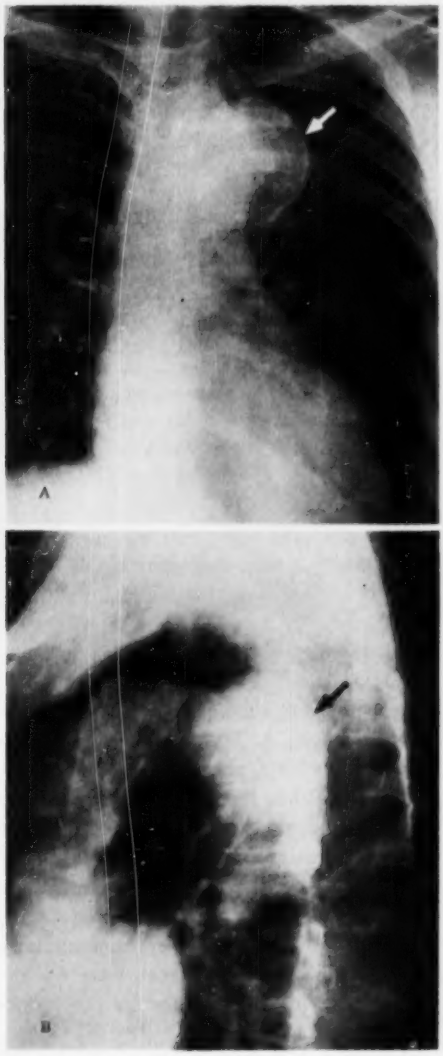
Fig. 6.—Angiocardiogram showing compression of the descending aorta, just beyond the origin of the left subclavian artery, by a huge dissecting hematoma (arrow), in a 49-year-old woman.

Fig. 7.—Angiocardiogram shows "buckling" of the right subclavian and carotid arteries.

be present in the right side of the neck and clavicular spaces. Figure 7 shows the angiocardiogram of a patient with widening of the right supra-aortic area. Tortuous (buckled) right subclavian and carotid arteries were responsible for the increased superior mediastinal shadow, which simulated a mediastinal tumor.

Traumatic Aneurysm of the Thoracic Aorta.—Traumatic aortic aneurysms may be produced by blunt or compression injuries or penetrating wounds. Formerly traumatic rupture of the aorta was thought to be rare and to result in sudden death, the diagnosis being made at autopsy. Angiocardiography and exploratory thoracotomy now make possible the diagnosis during life.[21]

Fig. 8.—Traumatic aneurysm of the aortic arch, in a 46-year-old woman with a history of an auto accident 26 years previously. *A*, conventional x-ray shows a huge calcified mass surrounding the aortic arch (arrow). *B*, left anterior oblique angiocardiogram reveals a saccular aneurysm at the aortic arch just beyond the origin of the left subclavian artery (arrow). Note the normal appearance of the rest of the aorta.



A common site of traumatic aortic aneurysms is the beginning of the descending aorta, just distal to the left subclavian artery and above the site of the ligamentum arteriosum. The other and more frequent site is in the ascending aorta just distal to the aortic valves. Both sites are fixed—the first by the brachiocephalic arteries, the other by the heart—and are subject to stress when the body decelerates after an injury.[22] This is because the relatively free central portions of the aorta are snapped forward by the retarding force and decelerate at a different rate than the rigidly fixed portions, which decelerate at the same rate as the body as a whole. The differential stresses cause aortic tears, which are usually horizontal; if they involve all layers there is rupture and sudden death. If a tear of the inner layers occurs, a saccular aneurysm results; if only the intima ruptures, a dissecting aneurysm is produced. Figure 8*A* demonstrates a calcified aortic aneurysm of the aortic arch in a 46-year-old woman who had had chest trauma during an automobile accident 26 years earlier. Angiocardiography (Fig. 8*B*) demonstrated the saccular nature of the aneurysm at the aortic arch. The normal contour of the ascending aorta was an aid in excluding the presence of syphilitic aortitis. The patient was asymptomatic, and the aneurysm was discovered after routine roentgenography of the chest. In view of the asymptomatic nature of the ailment, aortic resection was not recommended. In a recent case reported by Sarot and Lazzarini [23] a 36-year-old woman had pain in the left shoulder and back and developed cough. At first, a posterior mediastinal tumor of neurogenic origin was suspected. When the vascular nature of the mass was demonstrated by angiocardiography, the significance of severe chest trauma and shock sustained in an auto accident 14 years previously was appreciated. Successful resection of the traumatic partially calcified saccular aneurysm of the aortic arch with suture of the ends to a graft was accomplished.

Congenital Malformations of the Thoracic Aorta

Coarctation of the Aorta.—The diagnosis of coarctation of the thoracic aorta is being made with greater frequency because of routine palpation and blood pressure determinations of the lower extremities and the recognition of the significance of rib notching. Even with clear-cut clinical manifestation of aortic coarctation it is desirable to visualize the coarctation to exclude multiple and unusual sites of coarctation and associated aneurysms and to determine the site and length of the coarctation. Angiocardiography (Fig. 9), despite reports to the contrary, can be depended upon to visualize the coarctation in almost every instance.[3,24]

Fig. 9.—Left anterior oblique angiocardiogram, showing coarctation of the thoracic aorta (arrow).

Congenital Aortic Sinus Aneurysms.—The aortic sinuses are three small dilatations in the wall of the aorta immediately above the aortic valves. Each sinus lies just above the attachment of an aortic cusp. The right and left coronary arteries usually originate within two of the aortic sinuses; however, they may emerge immediately distal to the aortic sinuses. The aortic sinuses and their corresponding aortic valves are named according to the source of the coronary arteries. Thus, the right and left coronary arteries emerge from the right and left aortic sinuses, respectively. The remaining

aortic sinus usually lies posteriorly, does not contain a coronary artery, and, according to the newest nomenclature, is designated as the noncoronary sinus.

The aortic sinuses are intracardiac and cannot be identified by conventional roentgenography. During angiocardiography they appear as small dilatations at the root of the aorta immediately above the aortic valves and are best visualized in the left anterior oblique projection. Inconstant filling of the coronary arteries during angiocardiography does not allow complete identification of the sinuses. However, in the left anterior oblique view the right coronary sinus is anterior and just behind the sternum. The aortic sinuses of Valsalva are in close relation to all the cardiac chambers, particularly the right atrium and ventricle. The superior vena cava and the pulmonary artery, the left ventricle, and the left atrium are adjacent.

Clinically, an imperforated congenital aortic sinus may be suspected when there is a harsh systolic murmur in the aortic area in patients with coarctation of the aorta, arachnodactyly, or pseudocoarctation. Aortic diastolic murmurs due to aortic regurgitation may also be present. The definitive diagnosis of an imperforated aortic sinus aneurysm can be made by angiocardiography (Fig. 10*A*, *B*). Surgical repair of ruptured aortic sinus aneurysms has been attempted in three instances.[25] Even though surgical repair has not as yet saved lives, attempts to correct the lesion must continue to be made.

Pseudocoarctation.—Congenital kinking of the aortic arch just distal to the origin of the left subclavian artery may simulate a superior mediastinal tumor. Indeed, the angiocardiographic studies (Fig. 10*A*, *B*) may duplicate the findings seen in coarctation of the aorta. The differentiation from a true coarctation depends upon the absence of arterial collaterals and normal lower extremity blood pressures.[26]

Patent Ductus Arteriosus with Reversal of Shunt.—The ordinary case of patent ductus arteriosus is easily recognized by the characteristic machinery murmur. An-

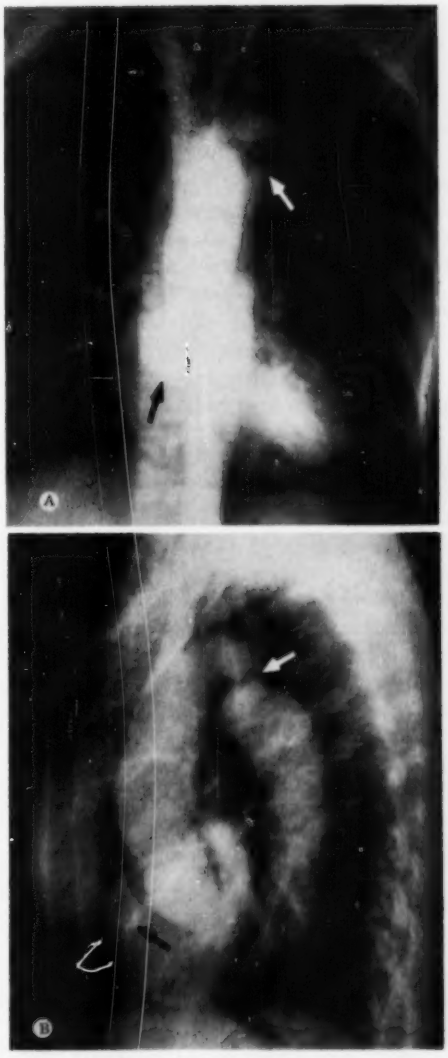


Fig. 10.—Congenital aortic sinus aneurysm and pseudocoarctation, in a 26-year-old woman. *A*, frontal angiocardiogram shows aneurysmal dilatation of aortic sinuses (arrow) and point of pseudocoarctation (arrow). *B*, left oblique angiocardiogram reveals the aneurysmal dilatation of the aortic sinuses; arrow points to right coronary artery. Note the point of pseudocoarctation (arrow) and the poststenotic dilatation of the descending aorta. Reproduced with permission from Steinberg,[25] *British Heart Journal*, British Medical Association.)

giocardiography and cardiac catheterization are usually unnecessary to make the diagnosis. If no complication like pulmonary

hypertension or cardiac failure intervenes, surgical correction can be postponed until the age of 8 years. The development of reversal of blood flow due to severe pulmonary hypertension, however, is a serious complication, and its recognition is important.[27] Angiocardiography has played a significant role in the recognition of the newly recognized syndrome of patent ductus arteriosus with reversal of shunt. Reversal of blood flow in a patent ductus arteriosus should be suspected clinically when the characteristic machinery murmur is altered and there is cyanosis and clubbing of the toes without similar changes in the fingers. This striking clinical phenomenon is due to pulmonary hypertension greater than the systemic blood pressure, producing reversal of the blood flow through the ductus, which is inserted distal to the origin of the left subclavian artery. The presence of unoxygenated blood in the descending aorta is responsible for the cyanosis and clubbing of the toes.

Figure 11 is the angiocardiogram of an infant who had the classical clinical signs of a reversed ductus. In addition, there was an enlarged left ventricle and aortic stenosis. Ligation of the ductus resulted in disappearance of the lower extremity cyanosis, but sudden death occurred 72 hours later. At necropsy fibroelastosis of the left ventricle and aortic stenosis was found.

Fig. 11.—Frontal angiocardiogram of a 4-month-old infant with classical cyanosis of lower trunk and extremities. Arrow points to ductus; note opacification of descending aorta (arrow), a pathognomonic sign of a reversed ductus arteriosus.

Comment

Opacification of the thoracic aorta (Figs. 1 to 10) by the intravenous method of angiocardiography has proved amply satisfactory for diagnosis of almost all aortic disorders. Rarely, when differentiation between an aortic septal defect and patent ductus arteriosus cannot be made by cardiac catheterization, injections of contrast material via a catheter that has been placed into the root of the aorta is necessary.[28] If the contrast material is seen to pass into the main pulmonary artery, the diagnosis of a septal defect can be made, whereas if the left pulmonary artery is opacified at a point beyond the origin of the left subclavian artery the lesion is a patent ductus arteriosus. For the diagnosis of subaortic stenosis, aortography via a catheter may occasionally be indicated.[29] Many unpleasant complications and even deaths have been reported after direct aortography, especially when highly concentrated contrast materials were used.[30]

Poor aortic opacification may occur in the patient in heart failure who has large dilated cardiac chambers and/or aortic regurgitation. Even in such circumstances, preliminary estimation of the circulation time with dehydrocholic acid (Decholin) and the making of serial exposures at the time of maximal aortic opacification will yield satisfactory studies.

Many of the failures to visualize the cardiovascular structures with the method of angiocardiography are due to lack of attention to a few physiologic details. In order to opacify the blood it is essential to add the contrast material rapidly. It is, therefore, necessary to use large-bore cannulas and syringes. The patient must be

instructed to avoid unconscious performance of the Valsalva maneuver, which shuts off blood flow into the superior vena cava and dissipates the contrast material into the collateral veins.[31] In some instances, undue elevation of the arm may exaggerate the physiologic point of constriction of the subclavian vein and prevent the entrance of the contrast material.

Figures 4*B* and 11 illustrate another advantage of angiocardiography over direct aortic opacification. In addition to outlining the saccular aneurysm of the aorta (Fig. 4*A*), serial study of the entire cardiovascular system also permitted the demonstration of stenosis of the left pulmonary artery (Fig. 4*B*). Similarly, Figure 11 shows reversal of blood flow through a patent ductus arteriosus from the left pulmonary artery; direct aortography would have demonstrated only the route through the patent ductus arteriosus.

For all these good and sufficient reasons, but chiefly because general anesthesia is unnecessary, the dangers inherent in chamber and great vessel puncture are avoided, and study of the entire cardiovascular system is secured, angiocardiography is preferred for visualization of the thoracic aorta.

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DISCUSSION

DR. JERE W. LORD JR., New York: Not only have I enjoyed Dr. Steinberg's paper immensely but I think all of us are very grateful and indebted to him and Dr. Robb for their pioneer work in the late thirties in making angiocardiography possible.

I should like to mention two points. In February of this year a patient was referred to us with the diagnosis of an ascending aortic aneurysm, made by a competent roentgenologist. I thought it would be wise to have it documented, and so Dr. Steinberg carried out an angiocardiogram, which indicated a mediastinal tumor.

The patient was bull-necked, and it was impossible to feel any goiter, but on exploration of the cervical area we found an intrathoracic goiter, which was removed without great difficulty and without opening the thorax, although preparations had been made to do so, if necessary.

Dr. Hinton, in discussing Dr. Steinberg's paper in New York, said that bleeding from a mediastinal goiter during removal is extraordinarily rare. It had been recommended to open the thorax, but it was not necessary to do so.

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Effects of Intra-Arterial Injection of Iodine Contrast Media on the Kidney of the Dog

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The literature pertaining to the development of aortography and to the occasional occurrence of serious injury of the spinal cord, mesenteric circulation, or kidneys has been referred to in previous reports from our laboratories [1,2] and has been reviewed more recently by McAfee and Willson.[3] Many authors emphasize the potential toxicity of contrast media to the kidney and the spinal cord. Our first report described an experimental method for producing injury of the spinal cord in dogs and compared the toxicity of two contrast media. Studies have continued in dogs in an attempt to standardize a similar technique for producing injury of a kidney. Idbohrn and Berg [4] have investigated injury of the rabbit's kidney by intra-arterial injection of contrast media and have reviewed earlier literature on experimental renal injury.

In our first study two contrast media were compared, sodium acetrizoate (Urokon Sodium) and iodopyracet (Diodrast). In the present study these two, together with diatrizoate (Hypaque) sodium and sodium diprotrizoate (Miokon Sodium) are compared. Two concentrations of each contrast medium have been used, 50% and 70%.

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The iodine content of acetrizoate is 65.8%, iodopyracet 49.8%, diatrizoate 59.9%, and diprotrizoate 57.3%. A comparison of the roentgen-opacity of a 50% solution of each of the contrast media is illustrated in Figure 1. Small test tubes of identical diameter separated by lead strips were placed upright before a bucky diaphragm and cassette, 84 cm. from the roentgen ray generator. Exposures were made for one second at 85, 80, 70, 60, 50, 40, and 30 kv. Maximum contrast was found at 50, 60, and 70 kv. Acetrizoate was the most opaque; diatrizoate, diprotrizoate, and iodopyracet followed in the order of their iodine content. The difference of opacity was consistent, whereas it is generally noted during clinical aortography or arteriography and in our animal experiments using the four agents that opacity of the visualized arteries varies widely. Acetrizoate ordinarily produced the best and most consistent visualization. An explanation for this variability and for the reported variations of toxicity has been sought.

Experiments have been of three types. The first tested the immediate effects of intra-aortic injection of a contrast medium. Injections were made at the level of the renal arteries. Effects were determined by acute experiments, with continuous registration of systemic blood pressure and of the volume of one kidney by use of a renal oncometer. The second determined late effects of intra-arterial injections. The agent was directed into one kidney through a puncture in its renal artery. Values for blood urea nitrogen and nonprotein nitrogen were obtained at intervals up to 21 days following the injection. The third experiment tested the

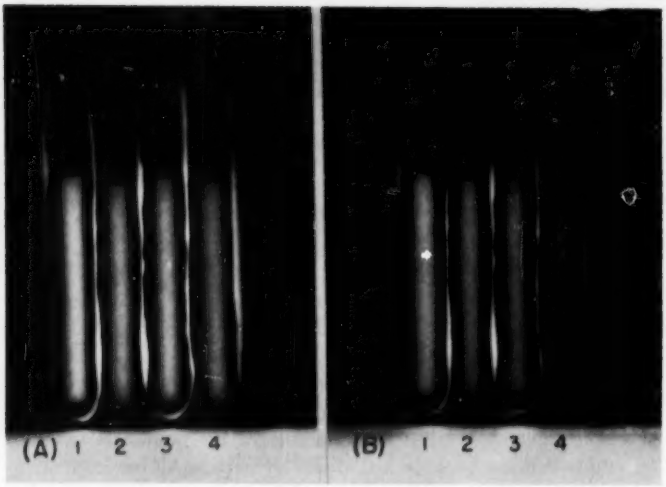


Fig. 1. — Roentgenograms at 50 kv. (*A*) and 70 kv. (*B*) illustrate the difference of roentgen-opacity of four test tubes filled with a 50% solution of acetrizoate (1), diatrizoate (2), diprotrizoate (3), and iodopyracet (4).

effect of position or gravity. The medium was injected into the midthoracic aorta with the dog placed on its side. Roentgenograms were obtained to demonstrate superior or inferior distribution of the contrast media.* Histopathological studies of both kidneys of each dog used in the experiments were performed by one of us (G. M.). The experimental observations will be presented first, and the histopathological studies, last.

Experimental Results

A. Plethysmographic Studies.—Twelve adult dogs weighing 7.2 and 14 kg. were anesthetized with pentobarbital sodium, 30 mg/kg. Systemic blood pressure was obtained by a cannula in the left femoral artery connected with a mercury manometer recording on kymograph paper. The right femoral artery was exposed, and a midline laparotomy incision was made. The renal oncometer was then placed about the left kidney without obstructing the arteries, veins, or nerves at the pedicle. The space within the oncometer was filled with a solution of saline containing 50 mg. of heparin in each 50 cc. to prevent clotting. Enough of this solution was used to fill the oncometer without filling its side-arm or the tubing which connected to the recording piston. This part of the system was filled with air. The writing arm from the piston registered continuously on the kymograph paper, above the record of the systemic blood pressure. A No. 16 polyethylene catheter was then introduced through the right femoral artery upward into the aorta until its tip lay at the level of origin of the renal arteries. Responsiveness of the plethysmograph was determined by intravenous injection of epinephrine, 1γ/kg. Since these dogs were in a supine position and spinal convulsions would otherwise occur, 0.3 mg/kg. of succinylcholine chloride (Anectine) was then administered intravenously. Injections of succinylcholine chloride were repeated at intervals of 30 to 40 minutes throughout the experiment. Respiration was maintained by an endotrachial catheter connected to a Palmer pump. The test contrast medium was then injected rapidly through the polyethylene catheter, with use of maximum manual force on a 25 or 50 cc. glass syringe. Time of injection varied from two to five seconds. The first injection was 5 cc. for acetrizoate and 10 cc. for the other three contrast media. At 30- to 40-minute intervals, successively increasing volumes of medium were injected until reactivity of the kidney ceased or the animal died. The concentration of the medium employed was 70% for acetrizoate and iodopyracet and 50% for diatrizoate and diprotrizoate.† Typical responses of blood pressure and renal volume for each of the four drugs are illustrated in Figure 2.

Acetrizoate (70%): The constriction of the kidney following the intravenous injection of epinephrine in three dogs averaged 1.25 cc., and the increase of blood pressure, 32 mm. Hg.

*It had been previously observed[1,2] that dogs receiving intra-aortic injections in the supine position were susceptible to cord injury and those in the prone position were not.

†These were the maximum concentrations furnished initially. Subsequently more concentrated solutions were supplied and these were mixed in later experiments to provide the 70% and 50% solutions of each agent.

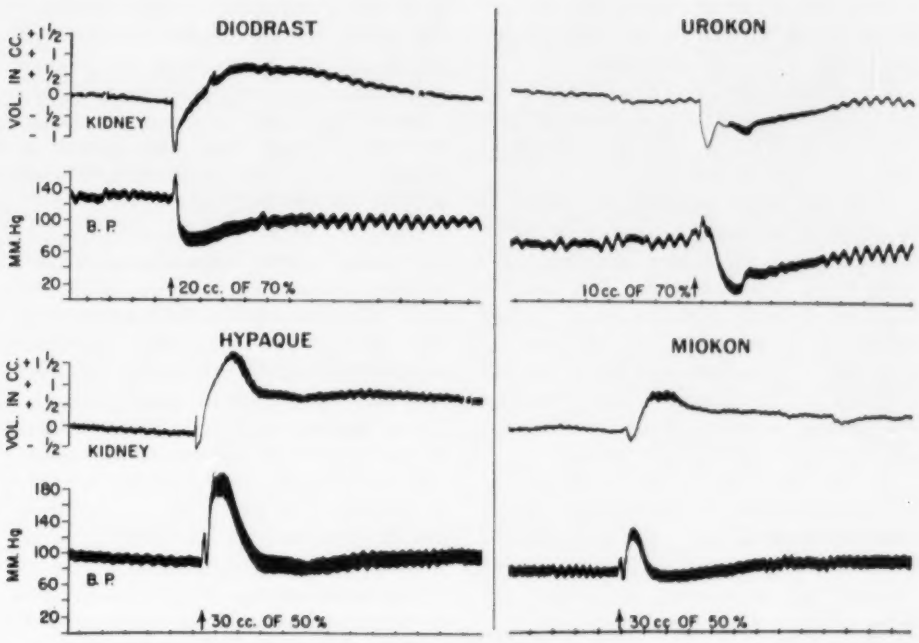


Fig. 2.—Typical changes of volume of the kidney and of blood pressure are presented. Prompt reduction of volume of the kidney and of systemic blood pressure occurred with iodopyracet and acetrizoate. Temporary passive dilatation of the kidney with increase of blood pressure occurred with diatrizoate and diprotrizoate. Pronounced responses occurred with 20 cc. of the 70% iodopyracet, 10 cc. of the 70% acetrizoate, and 30 cc. of each of the 50% diatrizoate and diprotrizoate.

With an initial intra-aortic injection of 5 cc. of acetrizoate there was a renal dilatation, 0.5 cc., lasting one and one-half minutes in one dog. In two dogs a prompt or active constriction of 1 cc. occurred, lasting 5 minutes in one animal and 40 in the other. In each of the three dogs the blood pressure was reduced promptly, the average being 52 mm. for 17 minutes.

A subsequent injection of 10 cc. of acetrizoate caused a prompt renal constriction in each dog, averaging 0.8 cc. In two this was followed by a dilatation, for an average time of 18 minutes. The constriction continued until the death of the third dog. In each dog the blood pressure fell promptly, an average of 50 mm. This lasted 10 minutes in two dogs. The third dog died in hypotension 30 minutes after the injection. Of the two dogs who survived the injection of 10 cc. of acetrizoate, one received additional injections. With 20 cc., the kidney actively constricted 2.5 cc. for 18 minutes. The blood pressure rose 36 mm. for 1 minute and then dropped 38 mm. for 10 minutes. A half hour later 25 cc. of acetrizoate was injected. Prompt active renal constriction and systemic hypotension occurred, with partial recovery 20 minutes later. Death occurred after an additional 30 cc. of acetrizoate, associated with terminal constriction and hypotension. The other dog who survived the 10 cc. injection was not given additional acetrizoate, since its kidney went into a secondary constriction 16 minutes afterward and never recovered toward a proper recording. It is evident that the plethysmographic tracing of each of these three dogs was definitely abnormal after a total accumulated dose of 15 cc. in two and of 35 cc. in the third. The blood pressure fell to shock levels after 15 cc. in

one animal and 60 cc. in another but continued normal for two hours in the one dog given only 15 cc. of acetrizoate.

Iodopyracet (70%): The constriction of the kidney following the epinephrine in three dogs averaged 1.7 cc., and the increase of blood pressure, 57 mm. Hg.

With the initial injection of 10 cc. of the contrast medium, a prompt or active constriction of the kidney occurred, averaging 1.1 cc., for 80 seconds. This was followed by moderate dilatation for an average duration of 17 minutes. The blood pressure was reduced promptly with the drug, the reduction averaging 60 mm. Hg. Thereafter the pressure recovered gradually; the average recovery time was six minutes.

A subsequent injection of 20 cc. of iodopyracet caused a prompt renal constriction averaging 1.7 cc. This was followed by renal dilatation for two minutes. Blood pressure fell an average of 50 mm. for three minutes. One animal then died in a convulsion. The remaining two were given an injection of 30 cc. Renal constriction averaged 1.1 cc., and reduction of blood pressure, 27 mm. Dilatation and recovery again followed.

Diatrizoate (50%): The constriction of the kidney in three dogs after the epinephrine averaged 1.1 cc., and the increase of blood pressure, 59 mm. Hg.

With the initial injection of 10 cc. of diatrizoate there was a slight constriction of the kidney, averaging 0.25 cc. for 30 seconds. This was followed by a definite and partially passive dilatation of 1.3 cc., which continued 18 to 35 minutes to the time of the next injection. The blood pressure did not fall in any animal. It rose 20 and 32 mm. for 90 seconds in two of the dogs and did not change in the third.

A subsequent injection of 20 cc. in each animal caused a prompt passive increase of renal volume averaging 0.7 cc. but lasting only two minutes. Blood pressure rose an average of 60 mm. for two and one-fourth minutes. With a 30 cc. injection a transient renal constriction, averaging 0.4 cc., occurred, and then a passive dilatation, averaging 0.8 cc. With 40 cc. the constriction was 0.3 cc. and the dilatation 1 cc. With the 30 and 40 cc. injections the increase of blood pressure was 80 and 64 mm. Hg.

Diprotrizoate (50%): The constriction of the kidney in three dogs after epinephrine averaged 0.9 cc., and the increase of blood pressure, 36 mm. Hg.

With the initial injection of 10 cc. of diprotrizoate a brief constriction of the kidney occurred, averaging 0.5 cc. for 30 seconds. This was followed by a definite dilatation, 0.6 cc. for 13 minutes. The blood pressure remained remarkably constant, there being no significant rise or fall.

A subsequent injection of 20 cc. of diprotrizoate in each animal caused a transient mild renal constriction of 0.5 cc., followed by moderate and partly passive dilatation, averaging 0.7 cc., for 12 minutes. Blood pressure did not fall; instead it rose an average of 65 mm. for 12 minutes. With a subsequent injection of 30 cc., a transient renal constriction again occurred. The subsequent renal dilatation was definitely increased, averaging 1.2 cc. With a 40 cc. injection the constriction was 0.8 cc. and the dilatation averaged 0.8 cc. With the 30 and 40 cc. injections the increases of blood pressure were 93 and 101 mm. Hg.

Histopathological examination of all kidneys at the end of each acute experiment revealed no recognizable changes.

B. Intra-Arterial Renal Injections.—The late effects of injection of contrast media into the renal arteries were studied in 32 recovery experiments. The 32 dogs weighed 6.8 to 22.7 kg. Each was anesthetized with pentobarbital sodium, and the abdomen was opened through a midline incision to expose the aorta and the renal vessels. Dogs were supine. Some variation of the arterial supply to the kidneys of the dogs was observed. The side with the longest primary renal artery, from the aorta to its first bifurcation, was selected for injection. An umbilical tape was passed beneath the origin of the artery at the aorta. Traction on the tape occluded the vessel momentarily and stabilized it. A 21-gauge curved needle was inserted into the lumen, and the test contrast medium was injected with moderate pressure. The tape was removed as soon as the injection had been completed. Finger pressure was used temporarily over the site of the needle puncture if necessary.

The abdomen was then closed, and the animals were allowed to recover and then kept under observation.

Groups of four dogs each were injected with 0.33 cc/kg. of a 50% solution of each test agent, and groups of four others, with a 70% solution of each medium. Not counted among the 32 dogs were 3 others who when killed had a thrombosis of the renal artery and infarction of one kidney. These were discarded. The 32 animals with successful operations were kept alive 1 to 29 days and then killed for autopsy.

At intervals from 1 to 29 days blood samples were obtained for urea and nonprotein nitrogen determinations, with use of a jugular vein needle puncture technique. All chemical determinations were made by one of us (H. M. T.). At autopsy the injected kidney was removed along with the normal or control kidney and the abdominal aorta and renal arteries. Arteries were carefully inspected for thrombus, grossly and histologically. None were found, since the three with thrombosis had been discarded. Specimens for histological examination were obtained from at least two areas of each kidney. Whenever an abnormality was visible, an area at the junction between normal and grossly abnormal cortex and medulla was selected for the sample. Specimens were fixed in formol-Zenker's-solution. Mounted sections were stained routinely with hemotoxylin and eosin. Selected sections were also stained with McManus periodic acid-Schiff method.

The number of days between injection and autopsy for the four dogs receiving 70% acetrizoate was 1, 18, 18, and 29; for 50%, 14, 20, 21, and 21; for 70% iodopyracet, 15, 15, 22, and 23; for 50%, 8, 9, 16, and 16; for 70% diatrizoate, 7, 10, 21, and 22; for 50%, 5, 11, 13, and 19; for 70% diprotrizoate, 6, 6, 6, and 20, and for 50%, 20, 21, 23, and 23. Since the only dog killed at one day showed a severe nephrosis and since the number of days for each of the groups was similar, no attempt is made to report gross and microscopic lesions in relation to the time of killing.

Nonprotein and Urea Nitrogen Values: Only one dog, the one killed at one day, had an elevated N. P. N., 81 mg. per 100 cc., and urea, 55 mg. per 100 cc. Blood samples were obtained from the 31 other dogs at intervals between 2 and 21 days following the injection of one renal artery. No significantly elevated values were obtained. The range of values of N. P. N. for the individual dogs was from 28 to 61 mg., and the range for urea nitrogen was from 7.8 to 36 mg. per 100 cc. For each group of dogs receiving the 70% solutions of the four contrast media, the average of values for N. P. N. were as follows: acetrizoate, 38.8; iodopyracet, 43.4; diatrizoate; 36.4, and diprotrizoate, 42.0 mg. per 100 cc. For the groups receiving the 50% solutions the averages were as follows: acetrizoate, 50; iodopyracet, 42; diatrizoate, 36.9, and diprotrizoate, 36.4 mg. per 100 cc. For urea nitrogen and the 70% injections the averages were as follows: 19.7, 20.5, 16.2 and 18.2 mg. per 100 cc., respectively. Although the urea nitrogen values for diatrizoate and diprotrizoate were a little lower than those for acetrizoate and iodopyracet, it is evident that there was no significant elevation, although the injected kidney of many of these animals was extensively damaged.

Gross Examination: Notes were made at the time of autopsy, and photographs were obtained of the ventral surfaces and of cross sections of each pair of kidneys. These

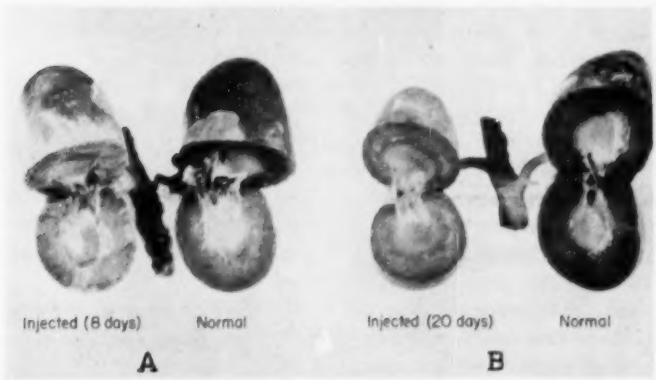


Fig. 3.—Cross sections of the two kidneys of one dog of the iodopyracet group (*A*) show normal appearance of control kidney and the patchy fading of color of the ventral or anterior half of the injected kidney caused by nephrosis. The kidneys of one dog of the acetrizoate group (*B*) show the decrease of size and uniform pallor of the injected kidney caused by nephrosis.

were used to estimate and compare the severity of damage. The control kidney, which had not been injected, was grossly normal in each animal.

Of the 32 dogs, there were 4 with a decrease of size of the injected kidney to a size one-third less than that of the opposite or control kidney (Fig. 3*B*.) Two of these had been injected with 70% acetrizoate and two with 50% acetrizoate. One of the remaining two dogs that received 70% acetrizoate exhibited several grayish brown areas and three smaller light gray scars on the ventral surface of the injected kidney. The other, the animal killed at one day, had a kidney which was swollen and dusky. One of the remaining two dogs who received 50% acetrizoate had a few scattered small gray-brown patchy areas of injury predominantly on the ventral surface and the ventral half of the cross section of the kidney (Fig. 3*A*). The other exhibited no significant lesion. Altogether, seven of the eight dogs receiving acetrizoate exhibited gross abnormalities in the injected kidney.

Of the four animals who received 70% iodopyracet, two had injected kidneys which seemed normal at the time of gross examination. Two had a diffuse faded pale brown color of the cortex. Of the four who received 50% iodopyracet, one had no gross lesion. Two had a diffuse pale brown color of the ventral half of the cortex of the kidney, and one had a diffuse faded brown color of the entire cortex.

In contrast, not one of the four animals receiving 70% diatrizoate or of the four animals receiving 50% diprotrizoate exhibited any gross lesion. Of the four animals receiving 50% diatrizoate, two had no gross lesions. Two had a homogeneous pale brown pallor of the cortex of the ventral half of the kidney. Of the four animals receiving 70% diprotrizoate, three exhibited no lesions. One had a homogeneous pale brown fading of the color of the entire cortex.

The fading of color of only the cortex of the ventral half of the kidney, that half which was anterior with the dogs supine at the time of the injection, is of interest. This occurred in 4 of the 28 dogs whose kidneys showed no significant decrease of size. This phenomenon is evident in Figure 3*A*. Also, one of the four dogs with a contracted kidney exhibited its most extensive cortical necrosis in the ventral or anterior half. It could not be determined whether this phenomenon was caused by injection into an anterior division of the renal artery.

Microscopic Examination: The type and extent of injury varied extensively. The convoluted tubular epithelium appeared most susceptible to the contrast media, but in the most severe lesions all renal elements were destroyed. In a few kidneys showing zonal involvement the border between the injured and the normal renal cortex was often abrupt. Occasionally the injury was focused on the tissue supplied by one branch of the arterial tree, the remainder of the kidney being spared.

For convenience of reporting, an arbitrary classification has been developed and the results are summarized in the Table. Eight of the thirty-two injected kidneys exhibited no lesion attributable to the contrast agent. These had been injected with diatrizoate or diprotrizoate. Twenty-four of the kidneys exhibited lesions attributable to the contrast media. These lesions are divided into four categories:

Cortical necrosis. This was a necrotizing effect, involving all tissue elements, glomeruli as well as tubules, affecting particularly the outer cortex but sometimes extending into the medulla.

Nephrosis, severe. This group showed an advanced tubular injury affecting all or virtually all nephrons throughout the kidney or over the distribution of a major extra renal branch of the renal artery.

Nephrosis, moderate. This group showed incomplete but quantitatively significant tubular involvement throughout or over the distribution of a major branch of the renal artery.

Nephrosis, slight. In these animals there was a mild focal tubular injury which was not quantitatively significant in extent.

Occurrence of Renal Injury Following Injection of Contrast Media into the Renal Artery of Thirty-Two Dogs

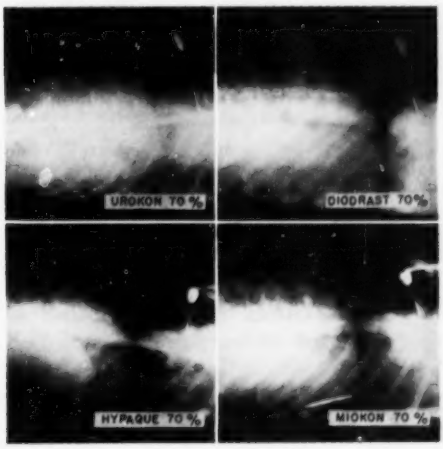
	Acetrizoate		Iodopyracet		Diatrizoate		Diprotrizoate	
	70%	50%	70%	50%	70%	50%	70%	50%
Dogs injected, no.	4	4	4	4	4	4	4	4
Degree of injury								
Cortical necrosis	2	0	0	0	0	0	0	0
Nephrosis, severe	2	2	2	1	1	1	1	0
Nephrosis, moderate	0	0	0	2	0	0	1	0
Nephrosis, slight	0	2	2	1	2	1	0	1
Dogs with injury, no.	4	4	4	4	3	2	2	1
Dogs without injury, no.	0	0	0	0	1	2	2	3

No lesions. No renal lesions attributable to the contrast agent were observed in these dogs.

It is evident that acetrizoate produced the more severe injuries, also that iodopyracet produced slightly less severe injuries. Each of these two agents produced an injury in each injected kidney. There seemed to be little difference of degree of injury in those kidneys injected by diatrizoate or diprotrizoate, but the frequency of injury was least in the diprotrizoate.

C. Positioning During Injection.—Sixteen dogs, four for each of the contrast media, were placed in a lateral position, right side down, for injection into the midthoracic aorta and for lateral roentgenograms. Pentobarbital sodium was used for anesthesia. The amount of contrast medium was 0.3 cc/kg. of dog weight, and the solution was 70%.

Fig. 4.—Typical aortograms using four contrast media injected with the dog on its side are compared. Acetrizoate best outlined the aorta. The dependent intercostal and renal arteries, when visualized, were somewhat better filled than the superior vessels.



The roentgen ray generator and the Bucky diaphragm and cassette were on a horizontal plane, with the back of the dog toward the film. Each injection was made by strong manual force on a 10 or 20 cc. syringe through an 18-gauge needle. The needle was directed downward through the left chest. Examples are presented in Figure 4.

Aorta: The amount of contrast medium injected, 0.3 cc/kg., was minimum for good visualization. The aorta was well visualized in three of four dogs injected with acetrizoate. It was visible but poorly outlined in three of four dogs of each group receiving iodopyracet, diatrizoate, and diprotrizoate.

Intercostal and Lumbar Arteries: Films were carefully reviewed to see whether there was any difference in the filling of segmental branches of the aorta which were directed upward by the lateral position as compared with those which were directed downward. Intercostal arteries were visualized in three of the four dogs receiving acetrizoate. The density of the dependent arteries was greater in two of the three dogs. The average number of arteries visualized was 5.7 on the upward side and 6 on the downward side. With iodopyracet the segmental arteries were visualized in each dog. The density of the dependent ones was twice that of the superior vessels. The average number of arteries visualized was 1.7 superiorly and 6 inferiorly. With diatrizoate the density of the inferior arteries was also twice that of the superior. The average number of arteries visualized was 4.2 superiorly and 6 inferiorly. With diprotrizoate the branches were not visualized in one dog. For the remaining three, the density of the inferior

arteries was twice that of the superior. An average of 2.3 arteries was visualized superiorly and 5.7 inferiorly.

Renal Arteries: With the minimum amount of contrast medium used, one or both renal arteries could be seen only in five dogs, three with acetrizoate and two with diatrizoate. On the inferior side the primary renal artery could be seen in each of the five and its first branches in four of the five. On the superior, or upper, side, the primary renal artery could be seen in only three of the five and the first branches in only one of the five.

It seemed evident, as the films were reviewed, that acetrizoate best visualized the aorta. With 1 exception, in all 16 dogs and for each agent the dependent intercostal arteries stood out more clearly but the number of arteries visualized inferiorly was only moderately greater than the number seen on the upward side. A somewhat greater difference occurred in those aortograms which visualized the renal arteries and branches. This difference was in favor of filling of the dependent arteries. This tendency to favor dependent filling could be an effect of gravity. Also it might be caused by streaming, since the needle injecting the contrast agent was directed downward.

Histopathological studies of each kidney were obtained in 16 of the dogs. There was no abnormality of either kidney attributable to the contrast medium in 15. Only one, acetrizoate-injected dog, demonstrated injury. There was a slight nephrosis of the upper kidney and a severe nephrosis of the dependent one at the time of autopsy, four days after the injection.

Comment

It is well established that opacity of contrast media to roentgen ray penetration parallels iodine content, as illustrated in Figure 1. Clinically and in our experiments there seems to be a greater variability of quality of visualization and of toxicity between the four contrast media studied than would be expected by the difference of iodine content alone. The medium with the greatest iodine content, acetrizoate, and the one with the lowest, iodopyracet, produced the most severe renal injuries. Diatrizoate and diprotrizoate with iodine concentrations approaching acetrizoate produced inferior visualization of the aorta and least injury. Hemodynamic effects of the contrast media suggest an explanation of these differences.

The rate of flow of blood through the aorta is a major factor in determining the amount of dilution of a contrast medium during and immediately after injection. Partial or complete obstruction of a diseased aorta of a patient, beyond the site of injection, would increase resistance and lessen flow of blood. This would decrease dilution of the medium at the moment of injection. With the aorta normally patent in patients or animals, a similar slowing of the flow of blood and decrease of dilution would occur if the contrast medium caused vasoconstriction beyond the site of injection or if it had a systemic effect which reduced blood pressure. Shaw [5] used toe plethysmography in patients receiving iodopyracet and acetrizoate for femoral arteriography and demonstrated vasoconstriction followed in a few minutes by a vasodilatation. Concentration and volume of the agent as well as pressure, time, and site of injection are other variables effecting intra-aortic dilution. These were kept reasonably constant in our experiments.

The plethysmographic studies indicate that acetrizoate and iodopyracet in the concentrations employed produced prompt and active decrease of volume of the kidney or renal vasoconstriction. At the same moment they reduced systemic blood pressure. These two immediate effects should decrease the rate of flow in the abdominal aorta and decrease the dilution of the contrast medium. The increase of opacity and improvement of visualization and the high incidence of damage to the kidney observed in the experiments could be explained on the basis of a relatively greater concentration of the medium. In contrast, the plethysmographic studies with diatrizoate and diprotrizoate indicate a prompt and to some

extent passive dilatation of the kidney with an increase of systemic blood pressure at the moment of injection. The relatively lower toxicity and the poorer detail of visualization in spite of high iodine content, observed with these two agents, could be explained by the resulting increase of flow and of dilution within the aorta. The subsequent dilatation or final constriction and loss of reactivity of the kidney in the acetrizoate and iodopyracet experiments seemed to be a result of injury.

These observations suggest the possibility that flow of blood in the aorta could be slowed by the intra-aortic injection of a vasoconstrictor drug prior to the injection of a contrast medium, or by the systemic administration of a drug which would cause hypotension, so that a smaller volume of the contrast medium might produce adequate visualization. Exploration of this possibility is the next step in the series of studies of contrast media.

Our observation [1] that dogs in the prone position are much less susceptible to cord injury during aortography than dogs in the supine position led to the further study of the relationship of position to distribution of contrast medium and injury, with use of a lateral position for the dog. The amount of each contrast medium selected for these experiments was small, 0.3 cc/kg. This permitted a better comparison of the upward or downward distribution of the contrast medium in branches of the aorta and observation of the relative opacity to roentgen ray penetration. The studies showed a definite tendency for the dependent vessels to fill and visualize better than the superior ones. Also, the only dog that developed renal injury had more damage in the dependent kidney than in the upper kidney.

For the time being, use of acetrizoate and iodopyracet in patients for aortography has been abandoned. Use for femoral arteriography continues. Our experiments have not definitely determined whether or not the difference in toxicity observed is inherent in the contrast agents themselves. They suggest that some of the difference may be related to inadequate dilution in the aorta and in tissues because of hemodynamic changes causing vasoconstriction in the vascular bed supplied by the aorta below the site of injection or systemic hypotension and thus decreasing flow and causing inadequate dilution by blood. Also, the experiments did not definitely determine whether or not the concentration of iodine in the medium is itself the factor determining toxicity. Nevertheless, it is significant that the drug with the lowest iodine content, iodopyracet, was high in relative toxicity. The techniques for production of spinal cord injury previously reported and those for renal injury now reported are applicable to further study of contrast media.

Summary and Conclusions

A technique for production of renal injury in dogs by injection of contrast media and a method of comparing these media are described.

Under the conditions of the experiments acetrizoate and iodopyracet have proved most injurious; diatrizoate and diprotrizoate, least injurious.

A reduction of systemic blood pressure and a constriction of renal volume occurring at the moment of injection are hemodynamic changes associated with greatest renal injury. A prompt increase of pressure and dilatation of the kidney are associated with least injury.

Duke University School of Medicine.

DISCUSSION

DR. EDWIN J. WYLIE, San Francisco: We have been particularly interested in the occurrence of renal damage following aortography, because it has been our most frequently encountered complication.

About three years ago, Dr. Frank Hinman, in our laboratory, investigated the various mechanisms that might potentially produce renal dysfunction following aortography and came to the conclusion that the pressure of injection had a great deal to do with some of the complications we were seeing. At that time he reported 6 patients, in a series of 300 aortographies, who had developed renal damage following aortography.

Subsequent reductioa of injection pressures has produced a marked lowering of the incidence of the severe forms of renal failure we had encountered. I have also adopted the practice of injecting distal to the renal artery take-off whenever this is feasible. Unfortunately, injection proximal to this level is usually necessary for accurate diagnosis when obstruction involves the aorta itself.

In the last 50 aortograms where injections were made proximal to the renal arteries, only one showed temporary reduction in PSP excretion after the procedure. Five others, however, showed reduction of creatinine clearance for periods varying from one week to two months. We believe that this latter study is of more value in determining the time when patients are suitable for subsequent operation and postpone later surgical procedures until the creatinine clearance has returned to normal.

Dr. M. E. DeBakey, Houston, Texas: The presentations concerned with aortography this morning, I think, have emphasized the importance and significance of this procedure.

First, it has, of course, been of definite importance in terms of providing precise information regarding the nature and location of the block and the presence or absence of a patent vessel below the block in occlusive arterial disease. Thus, from a surgical standpoint it is a very useful procedure.

It is not, however, a procedure without danger, and deaths have been recorded with sufficient frequency to make it extremely important to reconsider its indications and clinical usefulness.

From our experience with its use in occlusive disease, some of which has been presented by Dr. Couves, along with the experimental observations that have been made, we have become convinced that it should be used only when it is not possible to obtain the information by any other means.

In the evaluation of patients with occlusive disease of the aorta, and particularly in the typical Leriche syndrome, the pattern of the disease, as found by operation, is fairly well defined in most of these cases and aortography is unnecessary.

In a patient, for example, with complete absence of both femoral pulses, it can be assumed that the block is above that level and probably is in the aorta or common iliac arteries. Under these circumstances, the block is almost invariably localized and the arteries below this level, either the femoral or popliteal arteries, are patent. This has been found to be true in the great majority of approximately 180 cases of this type in which operation has been performed. Accordingly, we now do not use aortography in such cases. On the other hand, in patients with manifestations of incomplete occlusion, the occlusive process is more likely to be diffuse and aortography is indicated in order to define precisely the nature and extent of the block.

Dr. C. M. Couves, London, England: We, too, have been interested for some time in the renal effects of Urokon, both in the experimental animal and in man. During the past four years we have performed approximately 350 aortograms. We have had six serious renal complications, three of which ended fatally.

In humans, our studies have consisted of inulin and PAH clearance studies for glomerular filtration rate and renal plasma flow before translumbar aortograms are carried out and for various intervals afterwards. We have done this now on 22 patients. In cases where damage occurred as judged by these studies, we have tried to relate it to dosage, to the type of occlusion present, or to other factors.

[Slide] This relates the damage to the type of occlusion present. Strangely, in those cases where the aorta was completely occluded, or nearly so, the number showing damage was very small. This is in contrast to the dog, where clamping the aorta below the renals before injection seems to lead to renal damage in a high percentage of cases.

[Slide] This is a patient in whom we inadvertantly injected 24 cc. of Urokon into the right renal artery. This is the visualization which is received. You can see the needle in the orifice of the right renal artery.

[Slide] This shows the renal function studies carried out for 48 hours. You can see that the function is virtually wiped out on this side. We have not carried out further studies, but we have every reason to believe there has been irreparable damage here.

[Slide] This relates the damage to the size of dosage. This has been our most important observation. Those patients showing renal damage are overwhelmingly in the group receiving the larger dosage.

Dismissing the factors of preexisting renal disease and inadvertant renal artery injection, we really feel at this time that the single factor in determining whether a patient will get renal damage following lumbar aortography is the dose delivered to the kidney.

Dr. Keith S. Grimson, Durham, N. C.: As you know, our studies have been directed toward testing and development of safer agents for use as contrast media. The first report dealt with mechanisms of injury of the spinal cord; this one deals with renal injury. I do not believe that we can state at this time that one agent is safe, or another not as safe. Also, for several reasons, there should not yet be an announced condemnation of a specific drug. I can tell you, however, that we are now more interested in drugs other than acetrizoate or iodopyracet.

I should like to thank Dr. Wylie for his discussion and emphasis on creatine clearance. Renal

function should be carefully reevaluated after aortography. Probably some deaths considered operative mortalities have instead occurred where aortography has been followed within a day or two by surgery and were caused by postoperative uremia. An interval of several days should be allowed between aortography and operation, and renal function should be carefully reexamined.

Dr. Wylie and Dr. Couves emphasized that pressure and volume are important. We prefer to think more in terms of dilution within the aorta. This is the site at which the selected volume injected may remain too concentrated because of inadequate dilution. The contrast medium must dilute in the aorta adequately before it flows with the arterial blood to the kidney or the spinal cord. Another safeguard is emphasis on posture. One would not want to perform an aortogram with a patient lying on his back. Present evidence is that this would increase the hazard to the spinal cord.

I want to agree with Dr. DeBakey. Not many years ago there was a general feeling that if one had only one thing to look at in a patient one would want to see an aortogram. This has probably been reversed in favor of a careful peripheral vascular examination. I am pleased to hear Dr. DeBakey emphasize that we should consider aortography in a patient only when specifically indicated.

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A Comparison of Heparin and Bishydroxycoumarin (Dicumarol) as Anticoagulants

Resistance to Tissue Thromboplastin

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I. Introduction

Heparin and bishydroxycoumarin (Dicumarol) have been available for clinical use as anticoagulants for about 18 years. The choice as to which to use has not always been easy. In instances where anticoagulant effect is immediately needed or in which it is required for a few days (less than four) only, heparin is the choice because of the early appearance and quick disappearance of its effect. If a long-term effect is needed over a matter of weeks, bishydroxycoumarin, or a drug with similar action, is widely used because of the disadvantages of heparin with respect to the necessity of parenteral injection and expense.

The decision as to which drug to employ when the duration of therapy is to be a matter of one or two weeks, a situation which is common in the therapy of thromboembolism, is not so simple. The drug selected has generally been that with which the physician has had the greatest experience.

Heparin seems to act as an antithrombin, an antiprothrombin, and an inhibitor of platelet agglutination [1]; bishydroxycoumarin, as an inhibitor of prothrombin [2] and of Factor VII (proconvertin) [3] formation. Although the exact mechanisms which initiate intravascular coagulation are not known and may be various, an alteration in some aspect of the thromboplastin mechanism seems the most probable. Alterations in the blood vessel lining, in peripheral platelet concentrations, or in amounts of circulating thromboplastin [4] have been the factors most frequently suspected.

Experimental work comparing the two types of drug has not been abundant. Kiesewetter and Shumacker,[5] using the technique of traumatization or sclerosing of veins and arteries in dogs, found little difference between the two drugs. Much difficulty was experienced in maintaining constant levels of anticoagulant effect in their animals. Wessler was able to demonstrate that heparin delayed coagulation in the clamped jugular vein of dogs to a significant extent, whereas bishydroxycoumarin in doses which decreased the prothrombin percentage below 10% did not do so.[6] Brown and MacMillan [7] in a clinical study found that the two types of drug were about equally effective in preventing, or not preventing, thrombosis. Although the prothrombin levels (one-stage prothrombin test) were generally between 10% and 30%, they often found levels below 10%. Dosages of the bishydroxycoumarin type of drugs used are not mentioned. They found a higher incidence of hemorrhagic complications and considerable difficulties with pain after injection in the heparin group. It is to be noted, however, that heparin was given in doses of 150 mg. (15,000 units) in 1.5 cc. of fluid intramuscularly every 12 hours, a method which gives a marked effect early

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and a lack of effect during the later part of the period and creates local hematomas.

The experimental work which has demonstrated that the bishydroxycoumarin type of drugs can prevent intravascular thrombosis has of necessity had to be done on animals all of whom have several times as much prothrombin as man.[8,9] Furthermore, the doses selected have given one-stage prothrombin times between 5 and 10 times normal, far above the "therapeutic" ranges for man.

It seemed, therefore, that, despite the objections which might be raised against an in vitro type of test, there was a place for an investigation of the resistance to a common tissue thromboplastin of human bloods made hypocoaguable to so-called "therapeutic" levels either by heparin or by bishydroxycoumarin. Studies were, therefore, directed at heparinized bloods with coagulation times between 20 and 40 minutes and bloods with prothrombin activities of 10% to 30% by the one-stage test. Studies were performed both by whole blood coagulation time and plasma recalcification time.

II. Materials

A. Thromboplastin.[7]—Human brain was freed from pia and blood vessels, washed, and the gray substance ground in a mortar to a fine emulsion with 0.9% sodium chloride solution. The emulsification was facilitated by the use of a mechanical blender (Waring model). The emulsion was diluted with 0.85% sodium chloride solution, to which 20% veronal buffer was added. Approximately 5 ml. of solution per gram of brain substance was used for the extraction. The extract was left standing for 2 hours at 45 C, after which it was centrifuged for 15 minutes at 3500 rpm. The precipitate was discarded, and the grayish colloidal solution frozen at −20 C in portions corresponding to the daily requirement. Before being used it was thawed at 37 C. This extract gave a Quick's prothrombin time on normal plasma of 15 seconds. When stored frozen at a temperature below −20 C, the extract has remained unchanged during many months.

Thromboplastin was diluted with 0.85% sodium chloride solution in the following strengths: 1/10, 1/15, 1/20, 1/25, 1/40, 1/50, 1/60, 1/75, and 1/100. The amounts of thromboplastin represented by 0.1 cc. of the suspensions were, respectively, 2.0, 1.5, 1.0, 0.8, 0.5, 0.4, 0.33, 0.27, and 0.2 mg. Because of the inability to control the degree of wetness of the original brain thromboplastin, the above amounts would have little significance if an attempt were made to reproduce them by using another brain similarly prepared. Since the same preparation was used throughout this work, however, the comparisons made are considered valid.

B. Sodium oxalate, 0.1 M.—Anhydrous (reagent grade) sodium oxalate, 1.34 gm., was dissolved in 100 ml. of purified (distilled) water.

C. Calcium chloride, 0.02 M.—Anhydrous (reagent grade) calcium chloride 0.222 gm., was dissolved in 100 ml. distilled water.

D. Heparin.—Heparin sodium (The Upjohn Company) 1000 U.S.P. units (or 10 mg.) per cubic centimeter was used.

III. Procedures and Results

A. The resistance to thromboplastin of blood heparinized in vitro studied by the coagulation time was compared with that of blood of "dicumarolized" patients studied by the plasma recalcification time.

1. *Procedures*

(*a*) Heparin Experiments: To tubes in triplicate containing the above amounts of thromboplastin in 0.1 cc. volume were added amounts of heparin as follows: 0.004, 0.005, 0.006 mg., and to each tube was then added 1 cc. of freshly drawn blood and the clotting time in glass was observed. The clotting time was measured by the Lee-White[11] method, one of the tubes being tilted for examination every 30 seconds until it clotted, when the second tube was similarly examined and finally the third tube. In order to facilitate determination of the end-point, glass beads were used in the tubes. The time of clotting of the third tube was taken as the coagulation time. The mean normal coagulation time as measured by this method was 9.8 minutes (±1.1 min.),* range 7 to 12 minutes, on 25 determinations. The mean coagulation time with 0.004 mg. of heparin added was 13.8 minutes (±2.9 min.), range 8 to 18 minutes on eight determinations. The mean coagulation time with 0.005 mg. heparin added was 31 minutes (±4.2 min.), range 23 to 40 minutes on 35 determinations. The mean coagulation time with 0.006 mg. heparin added was 47 minutes (±2.9 min.), range 45 to 51 minutes, on six determinations. Thus evaluation of varying "therapeutic" levels of heparin was possible.

* Throughout this report the figures given in parentheses after the ± sign denote the standard deviation,

$$\text{or } \sqrt{\frac{\Sigma^2}{N-1}}$$

TABLE 1.—*Effect of Thromboplastin on Whole Blood Heparinized in Vitro: Coagulation Time*

Heparin, Mg./Cc.	Thromboplastin, Mg.							
	0	0.2	0.27	0.33	0.4	0.5	0.8	2.0
	Mean Coagulation Time, Min.							
0	9.8±1.1 (range, 7-12)	7.0±1.1	5.0±0.85	3.7±0.76	3.7±1.2	3.2±0.61	2.8±0.90	1.5±0.35
0.004	13.8±2.9	12.0±2.2						
0.005	31.0±4.2	31.4±4.1	23.0±1.6	14.3±1.6	10.1±2.1	10.3±1.7	6.6±2.1	5.2±0.6
0.006	47.0±2.9	49.5±6.6	43.5±2.0	39.8±2.1	38.2±2.5	32.8±2.3	17.5±1.7	9.0±1.0

(*b*) Bishydroxycoumarin Experiments: To tubes containing the varying amounts of thromboplastin listed was added 0.1 cc. of oxalated plasma (0.5 cc. of 0.1 M potassium oxalate per 4.5 cc. of blood). The plasma was obtained from blood drawn by strictly atraumatic venipuncture, the first-drawn 2 cc. of which were discarded and the remainder poured slowly into oxalate in a 15 cc. centrifuge tube. The tubes were stoppered, gently mixed, and centrifuged at an interval which varied between 15 minutes and 2 hours later at 1000 rpm for 15 minutes at 15 C. The plasma was then pipetted off into a glass test tube, which served as the supply for the recalcification time tests, which were then done within 15 minutes after centrifuging. The tests were done by adding 0.1 cc. of 0.02 M calcium chloride to the tube containing the plasma, the temperature of which had been equilibrated at 37 C in a water bath prior to the addition of the calcium. The clotting time of the plasma was measured by tilting the tube every 30 seconds, the tube being reimmersed in the water bath between tiltings. The first fibrin strands noted were taken as the end-point.

The method used, therefore, was the recalcification time of plasma, a test which has been employed to assay the identical factors which affect the whole blood coagulation time.[18] On 18 duplicate (36 total) observations on normals, the test showed a range of 2.0 to 2.6 minutes (120 to 160 seconds), with a mean of 2.25 (±0.25) minutes or 133 (±15) seconds.

Twelve tests on dicumarolized plasmas showing 10 to 19.9% prothrombin activity gave a mean recalcification time of 18.3 minutes (±3.8 minutes) and a range of 11.5 to 26.0 minutes.

Thirty tests on dicumarolized plasmas with 20% to 29.9% prothrombin activity gave a mean recalcification time of 16.5 minutes (±5.8 min.), with a range of 11 to 30 minutes. The test plasmas were those of patients receiving bishydroxycoumarin for therapeutic reasons on which the degree of hypoprothrombinemia was measured by the one-stage prothrombin test of Quick,[19] for which commercial (Difco) rabbit brain thromboplastin was used. In those experiments in which human brain thromboplastin was added to the recalcification time system the thromboplastin was added just before the calcium. Although experiments were made on dicumarolized plasma showing all concentrations of prothrombin from 10% to 100%, plasmas which showed greater than 30% prothrombin concentration returned to normal recalcification times on the addition of the smallest amount of thromboplastin used, namely, 0.2 mg. All larger amounts of thromboplastin gave readings below the lowest normal of 120 seconds. Only the results, therefore, on the plasmas with prothrombin concentrations below 30% are reported.

2. Results

(*a*) Heparin: Table 1 shows the results of the experiments using heparin. The 0.004 mg. heparin blood (coagulation time 13.8 min.) was reduced to a normal coagulation time by 0.2 mg. of thromboplastin (the least amount added in any of the mixtures).

TABLE 2.—*Effect of Thromboplastin on Oxalated Plasma from Dicumarolized Blood: Recalcification Time*

Prothrombin, %	Thromboplastin, Mg.							
	0	0.2	0.27	0.33	0.4	0.5	0.8	2.0
	Mean Recalcification Time, Sec.							
100	133±15 (range, 120-160)	64±5.8	54±6.6	49±3.8	48±3.2	41±2.6	35±1.4	33±2.4
20-29.9	990±348	169±41	145±19	132±18	119±17	110±12	93±8.6	71±13
10-19.9	1098±228	224±25	166±17	161± 9.8	153±38	136±19	127±21	90±5.1

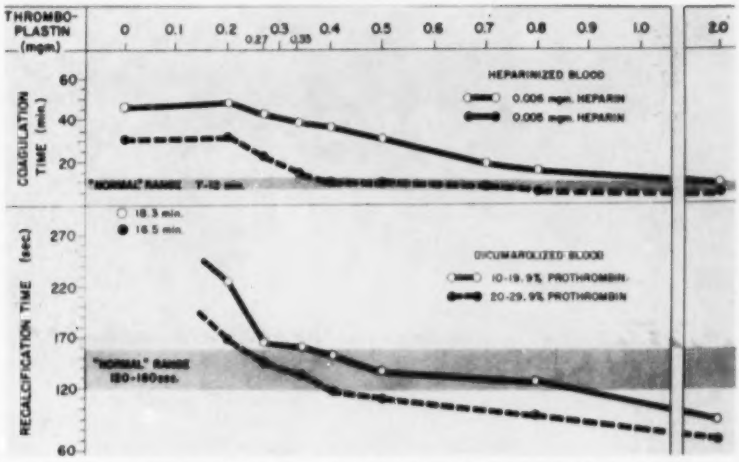

Chart 1.—Effect of thromboplastin on heparinized and dicumarolized bloods. Heparin was added in vitro. Method of coagulation time was used on heparinized bloods; recalcification time, on dicumarolized bloods.

The 0.005 mg. heparin blood (coagulation time 31 min.) was reduced to normal by an amount of thromboplastin between 0.33 mg. and 0.4 mg. and to below normal by an amount between 0.8 and 2.0 mg.

The 0.006 mg. heparin blood (coagulation time 47 minutes) was reduced to normal coagulation time by an amount of thromboplastin between 0.8 and 2.0 mg.

(*b*) Bishydroxycoumarin: Table 2 shows the results of the experiments using bishydroxycoumarin. The 20% to 29.9% prothrombin plasmas were reduced to normal recalcification time by addition of between 0.2 and 0.27 mg. of thromboplastin and to below normal by 0.4 mg.

The 10% to 19.9% prothrombin plasmas were reduced to normal by an amount of thromboplastin between 0.33 and 0.4 mg. and to below normal by an amount between 0.8 and 2.0 mg.

Chart 1 shows diagrammatically the comparative results of the heparin and bishydroxycoumarin experiments.

3. *Comment*

Blood which was dicumarolized to a level of prothrombin between 10% to 19.9% seemed to have the same resistance to thromboplastin as blood which had been heparinized to a coagulation time of 30 minutes. Blood which had been heparinized to a coagulation time of about 40 minutes was superior in thromboplastin resistance to the aforementioned bloods. Blood which had a coagulation time under the influence of heparin of about 14 minutes was poorly resistant to thromboplastin and in this respect was similar to blood dicumarolized to a level of between 20% and 29.9% prothrombin.

B. The resistance to thromboplastin of blood of heparinized patients studied by the coagulation time was compared with that of blood of dicumarolized patients studied by the plasma recalcification time.

1. *Procedures*

(*a*) Heparin Experiments: Between 25 and 50 mg. of heparin was given intravenously to patients. Bloods were drawn between 15 minutes and 2 hours after the injection of heparin. Coagulation times were done in the absence and in the presence of amounts of thromboplastin similar to those already used. Bloods with coagulation times of between 12 and 37 minutes were procured.

(*b*) Bishydroxycoumarin Experiments: The results from the previous bishydroxycoumarin experiments were used.

2. *Results*

Table 3 demonstrates that if the initial coagulation time was over 25 minutes a normal coagulation time was not procured

TABLE 3.—*Effect of Thromboplastin on Blood from Heparinized Patients: Coagulation Time*

Blood No.	Thromboplastin, Mg.											
	0	0.2	0.27	0.33	0.4	0.5	0.6	0.7	0.8	1.0	1.5	2.0
	Coagulation Time, Min.											
1	38									9.5	8.0	6.0
2	37				17				12	10		9
3	36	28	24		19				15			
4	36									8.0	6.5	5.5
5	35	28.5	27	25.5	20.5				18			
6	35									6	4	3.5
7	33									7.5	5.5	4.5
8	32.5	30.5	26.5	23.0	20				17.5			
9	26	23	20	18	15				13			
10	26	22	18		17				13			
11	24	19	16		12				10			
12	17	14	12		10				9			
13	16	13	11		9				7			
14	13				5				4	3		2
15	12	8	7		5				4			

by the addition of increasing amounts of thromboplastin until after 0.8 mg. of thromboplastin had been added. If the initial coagulation time was below 25 minutes, the coagulation time had come to normal by the time 0.4 mg. of thromboplastin had been added.

3. *Comment*

It is to be noted that in Chart 2 the curve representing the bloods with initial coagulation times of over 20 minutes and having a mean coagulation time of 31 minutes showed a greater resistance to thromboplastin than did the in vitro 0.005 mg. heparin bloods having an initial mean coagulation time of 31 minutes. Thus blood heparinized in vivo seemed to demonstrate a greater resistance to thromboplastin than did that heparinized in vitro, but it had a similar coagulation time. Thus the blood heparinized in vivo also showed a resistance to thromboplastin greater than the blood dicumarolized to a level of between 10% and 19.9% prothrombin.

C. The resistance to thromboplastin of blood heparinized in vitro was compared

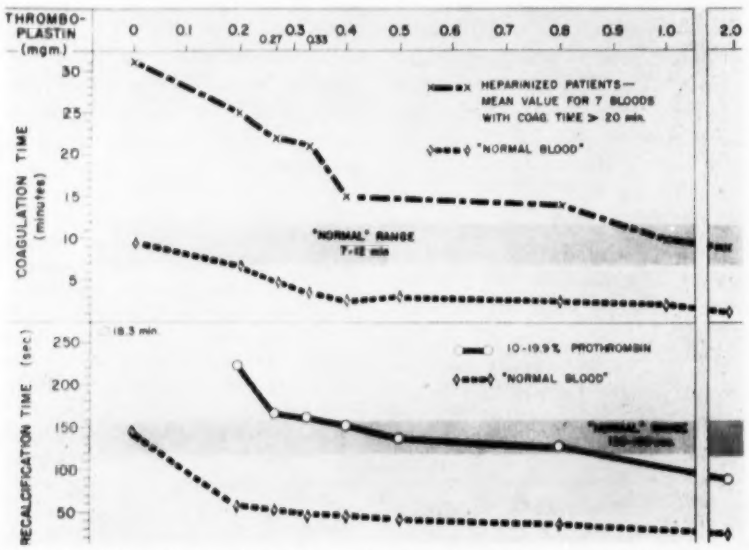

Chart 2.—Effect of thromboplastin on heparinized and dicumarolized bloods. Heparin was administered in vivo. Method of coagulation time was used on heparinized bloods; recalcification time, on dicumarolized bloods.

TABLE 4.—*Effect of Thromboplastin on Blood Heparinized in Vitro*

Heparin, Mg./Ml.	Blood No.	No Thromboplastin C.T.,* Min.	No Thromboplastin R.T.,† Min.	Thromboplastin, Mg. 0.2	0.27	0.33	0.4	0.5	0.6	0.7	0.8	1.0	1.5	2.0
				Plasma Recalcification Time, Min. (Normal 2.0-2.6 Min.)										
0.005	1			9.7	8.3	7.5	5.5	5.3		4.3	3.7			2.3
	2		17.5	11.7	10.7	9.3	7.7	6.5		6.0	4.3			2.3
	3		20.5								3.8	3.2	2.9	2.2
	4	28	17.5								3.1	3.0	2.7	2.5
	5	27	16.3								3.3	3.0	2.9	2.5
	6	32	21.7								4.3	3.7	3.1	2.2
0.006	7	36.5	22	16.5	13.7	12.5	8.0	5.2			4.2			2.7
	8	34.5	18.2	15.5	12.2	11.0	8.5	6.5			4.7			3.2
	9		20.8	14.5	12.8	10.5	9.0	8.0		5.6	3.5			3.0

* Coagulation Time
† Recalcification Time

with that of blood of dicumarolized patients, both studied by the plasma recalcification time method.

1. *Procedures*

(*a*) Heparin Experiments: Blood was drawn and added to oxalate in a manner similar to that described for the bishydroxycoumarin experiments except that heparin in 0.005 or 0.006 mg. amounts per cubic centimeter of blood had been previously added to oxalate. Recalcification times were carried out in a manner identical to that previously described, the thromboplastin being added just prior to the addition of the calcium.

(*b*) Bishydroxycoumarin Experiments: In this section, as in the previous one, the initial bishydroxycoumarin experiments are used for comparison.

2. *Results*

Blood heparinized with 0.005 mg. of heparin per cubic centimeter could not be converted to a normal recalcification time until between 1.5 and 2.0 mg. of thromboplastin had been added. Blood with 0.006 mg. of heparin per cubic centimeter did not reach normal recalcification time even with 2.0 mg. of thromboplastin (Table 4).

3. *Comment*

Chart 3 shows that by this technique the heparinized blood seemed to be much more resistant to thromboplastin than did the dicumarolized blood.

It is to be noted that the recalcification time of the heparinized plasmas had an absolute value of between one-half and two-thirds of the coagulation time of whole blood. It is not known whether this is due to liberation of thromboplastin in the additional manipulation of the blood necessary for production of plasma or whether there

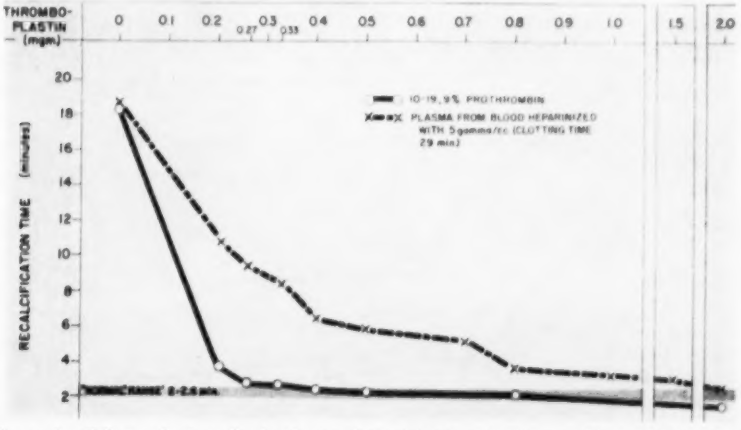

Chart 3.—Effect of thromboplastin on heparinized and dicumarolized bloods. Heparin added in vitro. Method of recalcification time was used for both heparinized and dicumarolized bloods.

TABLE 5.—*Effect of Thromboplastin on Dicumarolized Whole Blood: Coagulation Time*

Prothrombin, %	Thromboplastin, Mg.							
	0	0.2	0.4	0.5	0.8	1.0	1.5	2.0
	Mean Coagulation Time, Min.							
20-29.9	19.1±2.5	9.3±1.1	7.4±.69	6.6±1.6	8.3±1.1	6.0±1.1	4.4±0.5	3.8±1.0
10-19.9	22±2.4	12.7±1.9	9.1±2.8	8.2±0.65	6.7±1.5	5.7±0.35	4.2±0.35	3.5±0.70

is some binding of circulating anticoagulant by the oxalate.[14]

D. The resistance to thromboplastin of blood of heparinized patients was compared with that of blood of dicumarolized patients, both studied by the coagulation time method.

1. *Procedures*

(*a*) Heparin Experiments: The previous heparin experiments in which clotting times were employed are used in this section.

(*b*) Bishydroxycoumarin Experiments: Blood was drawn from patients who had received bishydroxycoumarin. Prothrombin activities and coagulation times were determined, the former on oxalated plasma in the usual way and the latter on whole blood. A group of values for coagulation times on plasmas having a prothrombin activity of between 10% and 30% are set forth in Table 5.

2. *Results*

All the dicumarolized bloods showed a return to normal coagulation time on the addition of the smallest amount of thromboplastin, namely, 0.2 mg.

3. *Comment*

Chart 4 shows a comparison of the dicumarolized bloods studied by the coagulation time with heparinized bloods studied by the coagulation time. It is to be noted that by this method the heparinized blood has a much greater resistance to thromboplastin. It is further to be noted, however, that in the higher amounts of thromboplastin, namely, 2 mg., the dicumarolized blood does still demonstrate residual resistance to thromboplastin in that the coagulation time is more than twice normal for the value procured with normal blood using the same amount of thromboplastin.

IV. General Comment

The methods used, namely, the recalcification time and the coagulation time, are notoriously inaccurate. They are the only ones we have, however, which measure the total action of the coagulation factors of

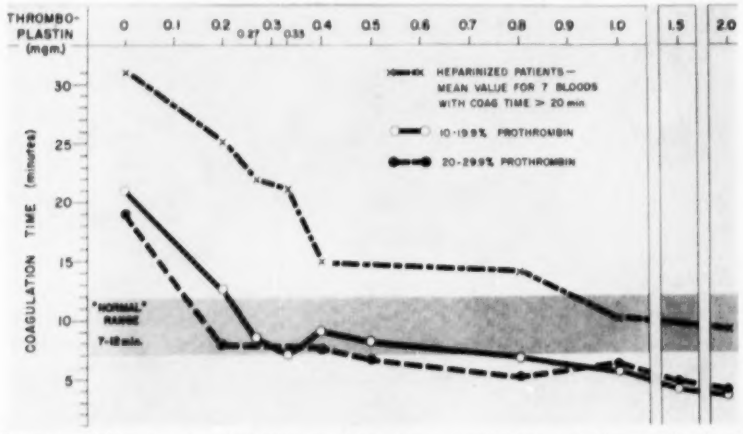

Chart 4.—Effect of thromboplastin on blood from heparinized and dicumarolized patients. Method of coagulation time was used in both.

the blood as they may occur in vitro. Siliconed tubes were not used, since we have found the reproducibility of the coagulation time in them to be less than in glass.

The data show that blood heparinized in vivo to a coagulation time of 30 minutes is more resistant to tissue thromboplastin in a test tube than is blood dicumarolized to a prothrombin activity of 10% to 19.9%.

If the blood was heparinized to a 30-minute coagulation time in vitro its resistance to thromboplastin studied by the coagulation time was the same as blood dicumarolized to 10% to 19.9% studied by the plasma recalcification time. But if the blood heparinized in vitro were studied by the plasma recalcification time its resistance to thromboplastin was greater than the dicumarolized blood.

The data therefore suggest that blood with a 30-minute coagulation under heparin is somewhat more effective in resisting thrombosis than is blood dicumarolized to a level between 10% and 19.9% of prothrombin activity.

There can, however, be no suggestion of total, or even important, ineffectiveness of the dicumarolized blood. The amounts of thromboplastin used were arbitrary. It is impossible to state how closely they may approach the ordinary stimulus to thrombosis in vivo. They were selected as amounts which tended to change the bloods as observed by the methods used, from hypocoagulable to hypercoagulable across the ranges of normal.

It is to be emphasized that both types of blood remained less coagulable than normal blood at the highest amount of thromboplastin (2.0 mg.) used. It cannot be denied that some anticoagulant effect, therefore, is felt in all bloods with abnormal prothrombin or clotting times, even of slight degree. What is unknown is the magnitude of the stimulus to coagulation against which protection is sought. It is doubtful whether this can ever be estimated, since it must differ for each clinical situation. An anticoagulation program, therefore, is unlikely ever to be either 100% effective or 100% ineffective. It appears, however, that in situations where the choice between heparin and bishydroxycoumarin from the point of view of convenience and duration of anticoagulant administration is even, then heparin should be chosen.

V. Summary

Dicumarolized and heparinized bloods were tested for resistance to varying amounts of tissue thromboplastin by the use of coagulation times and recalcification times.

By both methods blood heparinized to a coagulation time of 30 minutes was markedly superior in anticoagulant effect to blood dicumarolized to a prothrombin activity of 20% to 30% and slightly, but definitely, superior to that dicumarolized to a prothrombin activity of 10% to 20%.

It is emphasized that the above inference that heparin is a better anticoagulant than bishydroxycoumarin should not mean that heparin, at the present time, should replace bishydroxycoumarin where long-term anticoagulants are needed.

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The Clinical Entity of Anterior Crural Ischemia

Report of Four Cases

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Ischemic gangrene in the inferior extremity characteristically involves the toes and integument of the foot. It is uncommon except for pressure ulcers, to have proximal death of tissue with unaffected distal parts. There is, however, an unusual condition in which isolated necrosis of the muscles of the anterior crural compartment occurs either as a result of overexertion or as a sequel of sudden arterial occlusion.

In the former, or functional, type, an otherwise healthy young adult suffers the onset of severe pain in the anterior leg shortly after some heavier prolonged exertion such as a long hike or athletic contest. Within a few hours, a marked inflammatory reaction appears on the anterolateral aspect of one or both legs. There are erythema, marked tenderness, and tense swelling localised over the anterior tibial musculature, usually with an accompanying foot-drop (Fig. 1). The peripheral pulses are all present.

Fig. 1.—Site of skin reaction in anterior crural ischemia.

Depending on the severity of the reaction in the muscle tissue, the clinical course varies from acute abscess formation requiring incision to an indolent process of slow resolution with fibrous tissue replacement. In the latter instance, the shrunken anterior tibial muscle becomes stony hard, with varying degrees of foot-drop.

This functional type of anterior crural ischemia was originally described by Sirbu [1] and Horn.[2] In 1949, Carter, Richards, and Zachary collected nine similar cases, of which seven presented this clinical picture.[3] On the basis of careful observation, electromyography, biopsy, and arteriography, they felt that the condition was one of muscle swelling following unusual exercise with compression myopathy going on to the type

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of necrosis seen in Volkmann's ischemia. The peroneal nerve lesion was similarly one of compression neuropathy. There was no evidence of an arterial lesion in any case, the peripheral pulses being uniformly present and the arteriograms normal. There have been other case reports of this condition.[4-6]

In contrast, there is little concerning the appearance of this clinical picture following arterial occlusion. In 1955, Watson[7] described two cases of presumptive popliteal embolus in which anterior crural pain, tenderness, and swelling followed without more distal involvement. One of his patients died shortly thereafter, but the other went on to slow resolution, with ligneous change in the anterior tibial muscle, contracture, and permanent foot-drop.

We wish to present four cases of sudden arterial occlusion in which the syndrome of anterior crural ischemia appeared. The differing levels of vascular obturation are significant in that an insight is thereby offered into the pathogenesis of this process and a close relationship suggested to the functional type described above.

Report of Cases

Case 1.—A 69-year-old merchant seaman was admitted to Mount Sinai Hospital on Feb. 3, 1953, a few hours after suffering the onset of sudden, sharp, persistent pain in the right calf and foot. He was a known sufferer from rheumatic heart disease and had had paroxysmal auricular fibrillation for years. The affected extremity was cool below the knee but not insensate. There was a bounding pulse in the upper popliteal fossa but none below. A diagnosis of embolus to the right popliteal artery with good collateral flow was made. Because of a previous history of bleeding peptic ulcer, anticoagulants could not be used. By the fifth day, a warm, reddened, edematous area appeared over the anterolateral aspect of the leg. There was some fever, and blood cultures were taken. Within 72 hours, the inflammatory process increased in extent, foot-drop appeared, and the possibility of a septic embolus was considered. Toward the end of the second week, the signs slowly abated, the dorsalis pedis pulse appeared, and the temperature became normal. Within five weeks the only residua were some hypalgesia and a foot-drop, for which a brace was applied. On follow-up in June, 1956, three and one-half years later, the patient was enjoying fair health, with a normal extremity.

Case 2.—A 56-year-old grocer had been treated on a previous admission for arteriosclerotic heart disease, angina pectoris syndrome, and diabetes mellitus. He was now admitted, on Nov. 29, 1955, in acute distress, with a history of sudden onset of acute abdominal pain several hours previously with radiation into the inferior extremities, which had become paralysed. His general condition was poor, with a pulse rate of 128 and blood pressure of 160/110. In view of the absence of femoral pulsations and the cold pallor of the legs, a diagnosis of aortic embolism was made. Despite a lengthy procedure and multiple arteriotomies, it was not possible to establish a vigorous blood flow in the arteriosclerotic vessels. Postoperatively, the left foot presented a cold dusky appearance but the right foot and leg were warm. Four days after the procedure, bilateral oval discolored swellings of the anterolateral crural regions were noted, although the feet seemed improved (Fig. 2). It was soon evident that the left foot would become gangrenous, but the patient died with uremia on the 12th day. It was noteworthy that the symmetric oval patches described above did not change by the time of death.

Case 3.—A 47-year-old housewife had suffered from rheumatic heart disease for years with occasional bouts of failure. Twenty-two hours before admission, on Feb. 13, 1954, she had suddenly experienced severe abdominal pain, which soon radiated down into the inferior extremities, which became numb and paralysed. Physical examination, in addition to the cardiac findings, revealed absence of any arterial pulse below the umbilicus. The feet and legs were cold, insensate, and of a pale, blotched color. It was evident that aortic embolization had occurred, with splitting into both iliac arteries. Despite bilateral embolectomy, the left leg became gangrenous, and a left midthigh amputation was performed on Feb. 24, 1954, by which time the right posterior tibial and dorsalis pedis pulses had returned. However, a patchy involvement of the right anterolateral crural skin and foot-drop were noted, despite the warm foot and leg. This condition continued to develop, with surrounding inflammatory reaction and deep induration into an oval granulating defect measuring 6 by 3 in. (15 by 7.5 cm.), with exposed tibial tendon in the wound. The peroneal palsy was complete. Two additional admissions in May, 1954, and July, 1954, were necessary before the granulating area could be successfully grafted (Fig. 3). At present, two and one-half years later, the foot-drop persists, necessitating the use of a brace.

Fig. 2.—Bilateral symmetrical anterior crural reactions in Case 2.

CASE 4.—A 51-year-old factory worker was admitted on Dec. 13, 1954, with a complaint of severe pain and numbness of the right foot and leg of four days' duration. The onset had been sudden, with no previous history of heart or vascular disease. Examination revealed a cold clammy leg with insensate toes which the patient could not move. Only the femoral pulse was palpable on the right; all pulses were present on the left. Oscillometry confirmed these findings. In view of all the data, a provisional diagnosis of lower femoral artery thrombosis was made and a conservative regimen was instituted. However, embolism of the popliteal artery could not be ruled out. Forty-eight hours after admission, an area of redness, tenderness, and swelling was noticed over the anterolateral leg. This progressed daily, and, although the possibility of mycotic aneurysm was considered, the correct diagnosis of deep necrosis in the anterior tibial compartment was made by the 10th day. On the 26th day, a few cubic centimeters of pus were aspirated, and the abscess was incised on the following day. There was no growth on culture. Shortly thereafter the patient was discharged with a granulating wound. At no time was there any disturbance of peroneal nerve function. On April 14, 1955, it was necessary to readmit the patient for complete evacuation of necrotic muscle and tendon. Within three months the wound was healed (Fig. 4). The patient recovered full use of the extremity.

Pathogenesis

In the four cases summarized above, the clinical picture of anterior crural ischemia without gross distal tissue involvement (except for one extremity in Case 2) was produced by arterial interruptions at different levels. There were two aortoiliac emboli, one popliteal embolus, and one probable lower femoral artery thrombosis. This is of significance in that there was diminished blood supply in most of the affected extrem-

Fig. 3.—Involved area in Case 3.

Fig. 4.—Involved area in Case 4.

ities, although only the tissues of the anterior crural compartment failed to survive. In short, the lesion is not one of infarction due to interruption of the anterior tibial blood supply alone.

The anatomic reason for the sensitivity of the contents of the anterior crural compartment to ischemia was pointed out by Campbell and Pennefather,[8] years ago. The narrow confines of this particular osteofascial space and the insulation of the contained musculature from collateral blood supply are anatomic facts (Fig. 5). In his excellent study of the pattern of arterial supply to the muscles of the inferior extremity, Edwards showed that the lack of significant collaterals to some muscles made them end-organs with the blood supply dependent on one vessel.[9]

An equally important factor affecting

Resumé of Cases

Pathogenesis	Lesion	Sequel
Embolism Rt. popliteal artery	Ant. crural reaction	Resolution (4 wk.), foot drop
Aortic embolism (split)	Bilateral ant. crural reaction	Death, 12 days
Aortic embolism	Rt. ant. crural necrosis, lft. thigh amputation	Ulceration; Grafting; Healed; 6 mo.; foot drop
Embolism Rt. popliteal artery	Ant. crural necrosis, drainage of abscess (sterile)	Healed; 6 mo.; foot drop

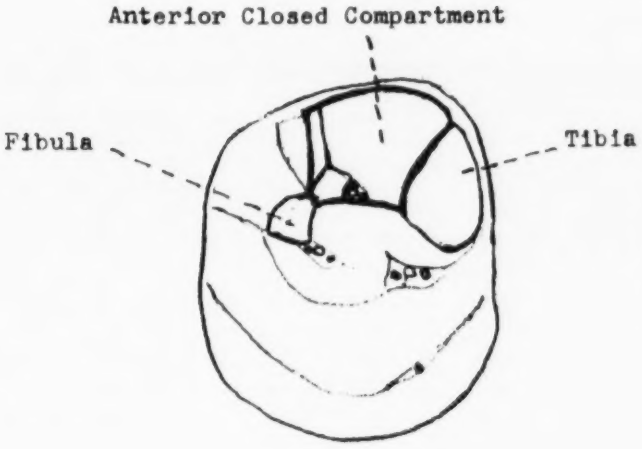

Fig. 5.—Cross section of midleg showing the narrow confines of the anterior crural compartment. The space is delimited by bony surfaces and firm fascia.

blood supply is the tendency of muscle to swell with the accumulation of lactic acid.[10] There is no surplus space in the anterior crural compartment, and as the fatigued or ischemic muscle increases in volume the resultant compression serves to further hinder blood flow and so increase the tendency to retain lactic acid. Horn[2] first offered this explanation for the muscle necrosis of the functional type of anterior crural ischemia. It serves equally well for those cases in which organic arterial occlusion has occurred, since the ischemia is not sufficiently complete to produce necrosis elsewhere in the extremity but does affect the confined musculature of the anterior crural space.

Treatment

Since the essence of therapy is early recognition of the nature of a lesion, it is important to keep the possibility of this condition in mind.

The most effective treatment is early release of tension in the anterior crural compartment by adequate incision of the anterior crural fascia. Where the lesion is of organic origin, any amelioration of the arterial occlusion such as embolectomy is, of course, remedial if performed in time.

Summary

The syndrome of anterior crural ischemia is a readily recognizable clinical entity. Distal tissues are characteristically uninvolved.

This condition is due to diminution of the blood supply to the muscles contained in the anterior crural compartment. This may arise from organic occlusion of the arterial vasculature of the extremity or from unusual exertion in persons susceptible to this lesion.

Such predisposition seems to have an anatomic factor in an apparently confined anterior crural space and a possible physiologic tendency toward the accumulation of high concentrations of lactic acid in the muscle tissue.

Treatment consists of early incision of the tense anterior crural space.

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Major Arterial Grafting in One Hundred Sixty-Nine Consecutive Cases

A Preliminary Report on Incidence of Success and Failure

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This analysis is presented as a preliminary report of results in arterial grafting. The longest follow-up is 27 months. All but one case received freeze-dried homografts sterilized in ethylene oxide.

Of the 169 cases, 102 were in the aortoiliac region, 63 were femoropopliteal, 3 were of the renal arteries, and 1 was a carotid artery. The anatomic locations are listed in Table 1. The unusually large number of femoral grafts in comparison with the number of aortic grafts results from many femoropopliteal grafts attempted in order to prevent amputation — even when the chance of success was poor. If these were omitted, the proportion of aortoiliac to femoropopliteal grafts (exclusive of aneurysms) would be approximately two to one in favor of the higher location.

Analysis of Results

A better understanding of the results may be obtained if the cases are divided under several headings: initial success, continued success, initial failure, and late failure. An initially successful graft is one in which pulses appeared in the proper locations distal to the graft following surgery. Initial failure is defined as a graft in which no pulses were present and no oscillometric improvement could be demonstrated postoperatively. A continued success is characterized by an asymptomatic patient with palpable pulses to the present time. A late failure is a case in which the graft failed at some time following the patient's discharge from the hospital.

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Suggested Classification for Patients with Arteriosclerosis Obliterans

We have not found enough practical difference among aneurysms to warrant segregation of these patients into groups. However, the following rough classification of degree of disease in patients with arteriosclerosis obliterans has proved to be of considerable value in assessing the condition of the patient both preoperatively and postoperatively. As is shown in Table 2, the patients were subgrouped both anatomically and clinically. The anatomic grade, determined solely by the ap-

TABLE 1.—*Anatomic Location of Grafts*

Site of Graft	Number of Cases			
	1st Year	2nd Year	3rd Year (3 Mo.)	Total
Aortic (ASO)	26	38	9	73
Common iliac	1	1	0	2
Aortic (aneurysm)	4	19	4	27
Femoral bifurcation	1	0	0	1
Femoral	9	41	8	58
Popliteal	1	3	0	4
Carotid	0	1	0	1
Renal	0	2	1	3
Totals	42	105	22	169

TABLE 2.—*Subclassification of Patients with Arteriosclerosis Obliterans*

Anatomic Grade
I. Segmental block
II. Multiple segmental or moderate diffuse with segmental block
III. Minimal exit flow
Clinical Grade
A. Claudication only
B. Marked rest pain, rubor, increased venous filling time, trophic changes
C. Gangrene

pearance of the angiograms, is divided into three groups indicated by the Roman numerals I, II, and III. Group I is those patients who have only a segmental block regardless of its length. Group II is those patients showing multiple segmental occlusions or diffuse disease of severe degree associated with segmental occlusion. Group III is those patients who have occlusion of a major artery without refilling of the parent vessel at a lower level and who, therefore, are entirely dependent upon collaterals from a point proximal to the occlusion. Clinically, the patients are also divided into three groups, A, B, and C. Group A is those patients who complain of intermittent claudication only. Group B is the patients who have definitive rest pain, marked rubor on dependency and pallor on elevation, increased venous filling time, and trophic changes in the foot. Group C is the patients with frank gangrene. By combining both subdivisions, therefore, patients may be graded from the most favorable rating, of I-A, to the least favorable rating, of III-C.

We consider patients with anatomic grades of I and II and a clinical grade of A as being good candidates for surgery, and these cases are consequently termed elective.

Patients with an anatomic grade of III and a clinical grade of B or C we consider to be poor-risk patients and so are termed nonelective. These definitions are arbitrary, but we believe them to be of practical significance.

Successes

Initial Success.—Table 3 indicates the initial success rate in this series. It will be noted that the percentage of grafts initially successful is remarkably similar year by year. Two figures are of particular significance. There is a decrease in the percentages of successful grafting in the femoropopliteal region between the first and second years and a slight decrease between the second and third years. The explanation for this is the increase in the number of these grafts attempted in poor-risk candidates who otherwise were threatened with amputation. From the nature of the risk, a large proportion of these grafts primarily are unsuccessful. The second point of interest lies in the fact that all aortic aneurysms were amenable to successful grafting at the time of surgery.

Continued Success.—Owing to 18 deaths and 5 late failures, it may be seen by references to Tables 3 and 4 that the percentage of continued success has dropped from an initial average of 86% to an average of 72%. One case of every four has proved a failure. One might presuppose that the majority of the failures would be in poor-risk candidates. If the cases are classified into subgroups based upon the severity of the disease and the clinical picture that they present upon admission, it may be seen that this is true.

Table 5 indicates the continued success rate in the various anatomic locations now subdivided into the above defined elective and nonelective groups. It may now be seen that 81% of those cases grafted electively have remained successful, whereas 44% of those cases grafted in the nonelective group have remained successful. The significant figure in this Table is the remaining high

TABLE 3.—*Initial Success*

Site of Graft	1st Year			2nd Year			3rd Year (3 Mo.)		
	Total	Initially Successful	%	Total	Initially Successful	%	Total	Initially Successful	%
Aortoiliac	27	24	89	39	36	92	9	9	100
Aortic aneurysm	4	4	100	19	19	100	4	4	100
Femoropopliteal	11	9	82	44	30	68	8	5	62
Carotid	0	...	...	1	1	100	0	...	...
Renal	0	...	...	2	2	100	1	1	100
Totals	42	37	88	105	88	84	22	19	86

TABLE 4.—*Continued Success*

Site of Graft	1st Year				2nd Year				3rd Year (3 Mo.)			
	Total	Initial Success	Continued Success	Failure	Total	Initial Success	Continued Success	Failure	Total	Initial Success	Continued Success	Failure
Aortoiliac	27	24	22	5	39	36	32	7	9	9	8	1
Aortic aneurysm	4	4	3	1	19	19	12	7	4	4	3	1
Femoropopliteal	11	9	6	5	44	30	28	16	8	5	5	3
Carotid	0	..	..	..	1	1	1	0	0	..	..	..
Renal	0	..	..	..	2	2	2	0	1	1	0	1
Totals	42	37	31 (74%)	11	105	88	75 (71%)	30	22	19	16 (73%)	6

TABLE 5.—*Continued Success*

Site of Graft	Elective				Nonelective			
	Total	Failure	Success	%	Total	Failure	Success	%
Aortoiliac	63	6	57	90	12	7	5	42
Aortic aneurysm	21	3	18	86	6	6	0	0
Femoropopliteal	42	15	27	65	21	9	12	57
Carotid	1	0	1	100	0	..	..	..
Renal	3	1	2	67	0	..	..	..
Totals	130	25	105	81	39	22	17	44

*See table 10 also.

failure rate in the femoropopliteal group. Whereas in the elective group the success rate for aortoiliac grafts is 90% and that for aortic aneurysm is 86%, the continued success rate in the femoropopliteal group is only 65%.

Failures

Before discussion of the failures, several general statements should be made. No amputations have been necessary because of failure of a graft in a patient who was not admitted with amputation in mind. Those patients who are listed as failures, exclusive of those who died, are patients in whom we are unable to find pulses distal to the graft. A fairly high percentage of these have decreased symptomatology and actually have had successful procedures as far as the clinical picture is concerned. They are, nonetheless, classified as failures, since we are unable to demonstrate patency of the graft. We do not believe that postoperative angiography is warranted as a general procedure.

Table 6 indicates the number of initial failures, late failures, and deaths in relation to each of the anatomic locations. It will be noted that the largest number of initial failures is in the femoropopliteal group and that the deaths are in the aortoiliac and aneurysm groups.

Initial Failure.—Table 7 represents a breakdown of the causes of the failures. Four of the initial failures were in the aorto-

TABLE 6.—*Failures* *

Site of Graft	Initial Failure	Late Failure	Death	Total
Aortoiliac	4	1	8	13
Aortic aneurysm	0	0	9	9
Femoropopliteal	20	3	1	24
Carotid	0	0	0	0
Renal	0	1	0	1
Totals	24	5	18	47

* There were 47 failures among the 169 cases (28%).

TABLE 7.—*Reasons for Initial Failure (24)*

Aortoiliac (4)					
1	I-A	Unknown			
1	II-B	Inadequate exit flow			
1	III-C	Inadequate exit flow			
1	III-C	Inadequate exit flow			
Aortic aneurysm (0)					
Femoropopliteal (20)					
8	II-B	III-C	III-C		
8	II-B	III-C	III-C	III-C	Inadequate exit flow
	II-B	III-C			
1	I-A	Unknown			
2	I-A	Unknown (clotting time 45 sec.)			
	I-A				
1	III-C	Polycythemia			
8	I-C	I-A	I-A		
	II-A	I-A	I-A	I-A	Bypass with cut-down thoracic grafts
	I-A	I-A			
Carotid (0)					
Renal (0)					

iliac group, and twenty were in the femoropopliteal. Of the four aortoiliac grafts, we are unable to explain one initial failure that occurred in a patient with a I-A classification. The other three are in the nonelective group, whose angiograms had the outstanding characteristic of very poor quality of vessels and failure of the occlusion to refill at a lower level. We have attributed the failure of these grafts to an "inadequate exit flow." By this we mean a limb whose remaining patent vessels below the distal end of the graft have a total blood-carrying capacity that is less than the volume of blood supplied by the graft. Under such circumstances, stagnation and slowed rate of flow occur within the graft and thrombosis is very likely to occur. In the femoropopliteal group, there were eight failures that we classed in the inadequate exit-flow group; one is unexplained; two occurred in patients with a rating of I-A but who seemed to have a markedly increased clotting tendency at the time of surgery despite entirely normal blood studies made postoperatively. Another was in a nonelective patient with true polycythemia. Eight occurred in patients who had bypass grafts. It will be seen that all but one of these were in the elective group. We have done a total of 16 bypass grafts in the femoropopliteal region, 8 of which were successful and 8 of which were failures. These are undoubtedly not significant figures and should not be interpreted as being a condemnation of the bypass procedure. Most of these were done before we had femoral arteries available, and the grafts consisted of cut-down thoracic aortas. This adds a further complication to interpretation of these grafts. Of specific interest in this Table are the small number of initial failures in the aortoiliac group as compared with those in the femoropopliteal group. Also of interest is the high proportion of patients with a condition compatible with the theory of inadequate exit flow as a cause of failure.

Late Failure.—The late failures in the series are listed in Table 8. One was in the aortoiliac group; one was a renal artery graft, and three were in the femoropopliteal group. These cases are listed. They are explainable on the basis of advancing disease, both in the patient's own arteries and in the graft itself, or as the result of trauma to the graft. We believe that the very small number of late failures is extremely encouraging, since an established successful graft has in the vast majority of cases remained successful.

TABLE 8.—*Late Failure (Exclusive of Death)*

No. of Cases	Anatomic and Clinical Grade or Graft	Cause of Late Failure
1	I-A	Diabetic; shut down femoral artery; graft at 4 mo.
1	I-A	Shut down one limb of aortic bifurcation at 1 yr.; regraft; new disease below
1	I-A	Ruptured femoral artery; graft at 8 mo. through arteriosclerotic plaque; regrafted
1	I-C	12 yr. old boy; shut down femoral artery; graft done for trauma; secondary surgery in same area
1	Renal	Ruptured anastamosis line at 10 days; nephrectomy

Deaths.—There has been a total of 18 deaths in this series, or 11% of the total. None of the deaths occurred in relation to grafts for aneurysm, of which only three grafts were in patients whose aneurysms were asymptomatic at the time of surgery. Eight deaths occurred in the aortoiliac group, and one death, in the femoropopliteal

TABLE 9.—*Primary Cause of Death*

No. of Deaths		Failure of Graft
3		Infection
7		Postoperative leak
	(1)	1st day
	(1)	11th day
	(1)	12th day (horseshoe kidney)
	(1)	14th day \ aortoenteric
	(1)	20th day / fistula
	(1)	5th month (aneurysm)
	(1)	1 year (own vessel friction)
10		Total
		Other Causes
3		Transfusion reaction
1		Pulmonary edema
1		4th day coronary occlusion
2		Ventricular fibrillation
1		Myohemoglobinuria
8		Total

group. Of the 18 deaths, we believe that 10 were the result of the graft procedure per se and that eight were due to conditions associated with major surgery but not specifically to the arterial graft. Of the 10 deaths that we attribute to the grafting procedure, three were of patients who developed retroperitoneal infection with erosion of the graft and a fatal massive hemorrhage. The remaining seven deaths were of patients who developed a postoperative leak and died because of hemorrhage. Several of the cases are of specific interest. One patient with an aortoiliac graft had a horseshoe kidney. It was elected to leave the kidney undivided, and the graft was placed under the transverse portion of the organ. On the 12th day the patient died of hemorrhage, and upon examination it was found that there was a leak in one common iliac limb of the graft, not at an anastomosis line and not at a point of a tied-off tributary vessel. It is our opinion that this represents a jet lesion as a result of partial compression of the graft at the point of the horseshoe with resultant poststenotic turbulence. Three patients died, one on the 14th day, one on the 20th day, and one in the 5th month, because of the development of aortoenteric fistulae at the proximal anastomosis line of grafts done for aneurysm. These were in early cases and represent technical failures that were due to poor anastomosis in markedly degenerated vessels. The final leak was in a man whose graft ruptured one year postoperatively. At the time of emergency operation it was found that his own iliac artery, which had been left in place at the time of the original bypass procedure, had retracted and so positioned itself that marked medial calcification present in this vessel was at right angles to the graft. This formed a set of calcific saw teeth over which the graft pulsated and finally eroded. The causes of death in the remaining eight patients are listed. Three were due to transfusion reactions and anuria. One patient developed an unexplained pulmonary edema several hours postoperatively; another suffered a coronary occlusion on the fourth postoperative day. Two, who were extremely poor surgical risks with leaking aneurysms, developed ventricular fibrillation that was irreversible. The final death in this group was of a patient in whom a gangrenous limb resulted from rupture of a popliteal artery; upon reestablishment of the circulation at the end of 36 hours, myohemoglobinemic nephrosis occurred because of absorption of toxic products from the nonviable limb, resulting in a renal shutdown.

Summary and Conclusion

In this series of 169 consecutive cases, the initial failure rate is 14%, the late failure rate 3%, and the mortality rate 11%. The continued success rate is 72%. These figures are not statistically significant, because of the small number of cases, but they do indicate the trend of arterial grafting in our institution. The commonest cause of initial failure has been an inadequate exit flow below the graft. The commonest cause of death has been postoperative leak. We believe that the most significant study in preoperative evaluation of the patient and his chances for successful grafting is through adequate angiography. We believe that angiograms should be made of all gangrenous and pregangrenous limbs, since approximately 50% of apparently irretrievable limbs can be saved by arterial grafting. The 81% continued success rate in elective cases encourages our belief that arterial grafting will continue to be useful in the treatment of arteriosclerosis obliterans that involves

TABLE 10.—*Results in All Cases, Including Ninety-One Additional Cases*

Site of Graft	Elective				Nonelective			
	Total	Failure	Success	%	Total	Failure	Success	%
Aortoiliac	88	7	81	92	20	8	12	60
Aortic aneurysm	30	3	27	90	11	7	4	37
Femoropopliteal	75	22	53	71	31	13	18	58
Carotid	1	0	1	100	0	--	--	--
Renal	4	1	3	75	0	--	--	--
Totals	198	33	165	83	62	28	34	55
Grand totals	260	61	199	77				

the large peripheral vessels and in the treatment of arteriosclerotic aneurysms.

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Addendum

Since this paper was submitted for publication, 91 additional grafts have been done. Results to the present time are summarized in Table 10. It is of interest to note that, whereas there has been one additional late failure in the aortoiliac group, there have been five late failures in the femoropopliteal grafts.

The Use of Autologous Venous Grafts in the Peripheral Arterial System

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The reconstruction of vital peripheral arteries continues to be an important problem to vascular and general surgeons. The more important indications for restitution of major arterial blood flow include the management of acute arterial injury and the sequelae of injury, such as traumatic aneurysms and arteriovenous fistulas. The increasing age of the general population has resulted in a larger number of patients who require surgical intervention for complications due to atherosclerosis of major arteries. The insertion of a graft may be necessary to bypass an obstructed arterial segment or to maintain arterial continuity in the treatment of an arteriosclerotic aneurysm. Finally, the insertion of a blood vessel graft is essential in the local excision of primary or metastatic tumors of the extremities and the neck which involve vital arteries.

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The present paper is a report of 21 autologous venous grafts introduced into the peripheral arterial circulation. We have defined peripheral to include those arteries distal to the inguinal ligament in the lower extremity and distal to the shoulder in the upper extremity.

Arterial Trauma

Five autologous venous grafts were inserted for trauma to the major artery of an extremity (Table 1). Two of these patients sustained laceration and avulsion of the skin over the upper thigh and inguinal regions resulting in contusion and thrombosis of the femoral artery. Patient 1 had a 4 cm. segment of superficial femoral vein inserted after resection of a segment of thrombosed superficial femoral artery. This graft was inserted on June 7, 1949, and was patent when the patient was last examined, on May 24, 1956. Patient 2, a 28-year-old white man, sustained a similar injury, necessitating the insertion of an 8 cm. greater saphenous vein segment from the common to superficial femoral arteries after the resec-

TABLE 1.—*The Use of Autologous Venous Grafts in Acute Peripheral Arterial Injury*

Patient	Age	Diagnosis	Donor Vein	Method of Anastomosis	Length of Graft, Cm.	Result
1	48	Laceration and contusion, rt. femoral artery	Superficial femoral, rt.	End-to-end after excision of traumatized arterial segment	4	Patent, 7 yr.
2	28	Contusion and thrombosis, lt. common and superficial femoral arteries	Greater saphenous, rt.	End-to-end after excision of traumatized arterial segment	8	Patent, 2 mo.
3	21	Thrombosis, lt. common and superficial femoral arteries following operative trauma	Greater saphenous, rt.	Bypass from ext. iliac to superficial femoral arteries, end-to-end anastomosis	18	Patent, 17 mo.
4	53	Contusion and thrombosis, rt. axillary artery	Greater saphenous, rt.	End-to-end after excision of traumatized arterial segment	6	Patent, 17 mo.
5	48	Contusion and thrombosis, lt. brachial artery	Cephalic, lt.	End-to-end after excision of traumatized arterial segment	5	Patent, 12 mo.

tion of a thrombosed artery. This graft was inserted on Nov. 4, 1953, and was known to be patent on Jan. 2, 1954. The patient subsequently required an amputation of a portion of the foot as a result of traumatic injury to this region. The graft was reported as being patent at that time. The third case of major arterial trauma to the lower extremity occurred in a 21-year-old woman (Patient 3), presumably during the course of a high saphenous ligation. Following this operation the extremity was noted to be cold, and no major arterial pulses were felt. Three weeks later (Dec. 23, 1954) an 18 cm. segment of greater saphenous vein was anastomosed end-to-end fashion to the external iliac and the superficial femoral arteries, bypassing the ligated segment. Distal pulses returned in the extremity and remained present when patient was last seen, on May 24, 1956.

There were two instances of trauma to the major artery of the upper extremity in this group. The first occurred in a 53-year-old white woman (Patient 4) who sustained a gunshot wound of the right axilla, with laceration and contusion of the distal portion of the axillary artery, on Jan. 17, 1954. A 6 cm. segment of greater saphenous vein was used to repair the axillary defect after excision of the traumatized artery. This graft was patent on June 1, 1955. The remaining patient (Patient 5) sustained a crushing wound of the left arm, with contusion and thrombosis of the brachial artery in its midportion. A 5 cm. segment of the brachial artery was excised, and a segment of cephalic vein was used as a graft. The graft was patent on a follow-up examination approximately one year after insertion.

Arterial Aneurysms

Reconstruction of major arterial continuity utilizing autologous vein grafts was performed in six cases of arterial aneurysm. Two of the aneurysms were traumatic in origin and four were arteriosclerotic in type. Five of the six aneurysms were situated in the lower extremity, and the sixth was in the brachial artery (Table 2).

The traumatic aneurysm of the brachial artery was in a 56-year-old Negro man (Patient 6). The aneurysm was in the distal third of the vessel and was treated by means of Matas reconstructive endoaneurysmorrhaphy procedure, utilizing a 6 cm. inlay venous graft obtained from the right basilic vein. Follow-up examination three years after surgery revealed the graft to be patent. The other traumatic arterial aneurysm was in a 21-year-old white man (Patient 7) and involved the distal third of the left superficial femoral artery and proximal

TABLE 2.—*The Use of Autologous Venous Grafts in Peripheral Arterial Aneurysms and A-V Fistula*

Patient	Age	Diagnosis	Donor Vein	Method of Anastomosis	Length of Graft, Cm.	Result
6	56	Traumatic aneurysm, rt. brachial artery	Basilic, rt.	Reconstructive endoaneurysmorrhaphy with inlay graft	6	Patent, 37 mo.
7	21	Traumatic Aneurysm and A-V fistula, lt. superficial femoral artery and vein	Greater saphenous, rt.	Obliterative endoaneurysmorrhaphy, ligation of superficial femoral vein and insertion of graft into arterial defect	7½	Patent, 20 mo.
8	72	Arteriosclerotic aneurysm, lt. external iliac and common femoral arteries	Greater saphenous, lt.	End-to-end after excision of aneurysm	3½	Patent, 6 mo.
9	47	Arteriosclerotic aneurysm, lt. popliteal artery	Greater saphenous, rt.	End-to-end after excision of aneurysm	8	Patent, 17 mo.
10	51	Arteriosclerotic aneurysm, rt. popliteal artery	Superficial femoral, rt.	End-to-end after excision of aneurysm	15	Patent, 26 mo.
10	51	Arteriosclerotic aneurysm, lt. popliteal artery	Greater saphenous, lt.	End-to-end after excision of aneurysm	9	Patent, 18 mo.

popliteal artery. In addition, the patient had an arteriovenous fistula at the junction of the popliteal and femoral artery and vein, with the proximal and distal ends of the artery and vein opening into the aneurysmal sac. A Matas obliterative endoaneurysmorhaphy was performed, and the defect in the artery was reconstructed with a 7.5 cm. segment of greater saphenous vein from the contralateral extremity. The proximal and distal ends of the vein were ligated. Follow-up examination 20 months after surgery revealed the graft to be patent.

The arteriosclerotic aneurysms all occurred in the lower extremity, and three of the four were in the popliteal artery. The remaining aneurysm was of the left external iliac and common femoral arteries in a 72-year-old white man (Patient 8). This aneurysm was excised, and the defect was reconstructed by means of a 3.5 cm. segment of greater saphenous vein. Follow-up examination six months later revealed patency of the graft. The three popliteal aneurysms were all treated by excision and interpolation of a venous autograft. The first was in a 47-year-old white man (Patient 9) and required an 8 cm. long graft from the greater saphenous vein. This was patent 17 months after insertion. The remaining two popliteal aneurysms occurred in the same patient (Patient 10), a 51-year-old white man. The excision of an acutely thrombosed aneurysm with the insertion of a 15 cm. graft from the right superficial femoral vein was performed by another surgeon.* Approximately eight months after this procedure the patient developed a right popliteal aneurysm. This was excised by us, and a 9 cm. segment of greater saphenous vein was employed to reconstruct the artery. Examination 26 and 18 months after the two operative procedures (Dec. 13, 1955) revealed both grafts to be patent.

Neoplastic Disease

Infrequently a soft tissue tumor of the extremities will be treated by local excision rather than amputation. This method of treatment may be utilized because of the low grade of malignancy of the tumor or because of the patient's refusal of a more radical procedure. The one case of this type in the present group was a leiomyosarcoma of the left upper thigh in a 54-year-old white man (Patient 11) (Table 3). The tumor completely encircled the common and superficial femoral vessels. A block resection was performed in conjunction with an inguinal node dissection, and a 12 cm. vein graft was inserted into the defect in the common and superficial femoral arteries. The right superficial femoral vein was used as the donor vessel. Fourteen months after the procedure a recurrence of the leiomyosarcoma was noted in the upper thigh, and the patient agreed to hemipelvectomy. Gross inspection of the venous autograft revealed it to be indistinguishable from the adjacent artery. It was patent, and there was no dilatation. Microscopic examination of the graft showed marked fibrous hyperplasia in all layers of the graft wall.

TABLE 3.—*The Use of an Autologous Venous Graft in the Resection of a Vital Peripheral Artery for Malignant Disease*

Patient	Age	Diagnosis	Donor Vein	Method of Anastomosis	Length of Graft, Cm.	Result
11	54	Leiomyosarcoma lt. thigh	Superficial femoral, rt.	End-to-end after excision of tumor	12	Patent, 14 mo. hemipelvectomy for recurrent sarcoma

Obliterative Arterial Disease

The excision of thrombosed segments of vital peripheral arteries with restoration of continuity has presented a constant challenge to the vascular surgeon. The direct interposition of a graft following resection of an obliterated segment has met with equivo-

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cal success. More recently the method of bypass grafting has been introduced by Linton [1] and Crawford and co-workers.[2] This technique has many theoretical advantages over the direct interposition procedure in the treatment of segmental obliterative arterial disease. We have inserted autologous venous grafts into the arterial system of the lower extremity nine times in the treatment of this condition. One of the grafts was directly introduced after excision of the occluded segments. The remaining eight grafts were inserted with use of the bypass method, leaving the thrombosed segment in situ (Table 4).

The remaining eight bypass procedures were performed during the preceding year in a total of six patients. The two patients in whom bilateral procedures were done were 62- (Patient 13) and 61- (Patient 14) year-old white men. The first patient (Patient 13) presented bilateral segmental thrombosis of the superficial femoral artery. This was treated by means of a 20 cm. graft in the left thigh and a 7 cm. graft in the right thigh. The greater saphenous vein served as the source of both grafts. Both of these grafts were patent five months postoperatively (Jan. 20, 1956). The second patient (Patient 14) had a bilateral common

TABLE 4.—*The Use of Autologous Venous Grafts in Obliterative Peripheral Arterial Disease*

Patient	Age	Diagnosis	Donor Vein	Method of Anastomosis	Length of Graft, Cm.	Result
12	61	Thrombosis of rt. superficial femoral artery	Superficial femoral, rt.	End-to-end after resection of thrombosed segment	7½	Patent for 4 wk.; thrombosed 5th wk.
13	62	Thrombosis, lt. superficial femoral artery	Greater saphenous, lt.	Bypass, midportion, lt. superficial femoral artery	20	Patent, 5 mo.
	62	Thrombosis, rt. superficial femoral artery	Greater saphenous, rt.	Bypass, midportion, rt. superficial femoral artery	7	Patent, 4½ mo.
14	61	Thrombosis, rt. ext. iliac and common femoral arteries	Greater saphenous, rt.	Bypass from ext. iliac to superficial femoral arteries	12½	Patent, 4 mo.
	61	Thrombosis, lt. ext. iliac and common and superficial femoral arteries	Greater saphenous, lt.	Bypass from ext. iliac to superficial femoral arteries	12½	Thrombosed within 1 wk.
15	58	Thrombosis, lt. superficial femoral artery	Greater saphenous, lt.	Bypass, midportion, lt. superficial femoral artery	11	Thrombosed within 1 wk.
16	59	Thrombosis, rt. superficial femoral artery	Greater saphenous, rt.	Bypass from ext. iliac to superficial femoral arteries	18	Patent for 3 wk.; thrombosed 4th wk.
17	63	Thrombosis, lt. superficial femoral artery	Greater saphenous, lt.	Bypass from ext. iliac to superficial femoral arteries	18	Patent, 5½ mo.
18	75	Thrombosis, lt. superficial femoral artery	Greater saphenous, lt.	Bypass from lt. common femoral to popliteal arteries	38	Graft ruptured 41 days after insertion; wound infection

The single instance of direct interposition was in a 61-year-old white man (Patient 12), who had a 5 cm. segment of thrombosed superficial femoral artery excised and end-to-end anastomosis of a 7.5 cm. segment of superficial femoral vein. This graft functioned initially, but disappearance of distal arterial pulsations indicating thrombosis was noted during the fifth week following operation. This procedure was performed in 1951.

and superficial femoral arterial thrombosis. Bilateral external iliac to superficial femoral artery bypass grafts utilizing the greater saphenous vein as a donor vessel were inserted. Both grafts measured 12.5 cm. in length. The right saphenous autograft was patent four months after operation, but the left thrombosed within one week of insertion.

In the four patients subjected to unilateral bypass procedures, early thrombosis oc-

curred in two patients (Patients 15 and 16). An 11 cm. greater saphenous graft was inserted for a left superficial femoral artery thrombosis (Patient 15) and an 18 cm. greater saphenous graft for a right superficial femoral artery thrombosis (Patient 16). A third member of the group (Patient 17) had an 18 cm. greater saphenous graft inserted for a segmental thrombosis of the left superficial femoral artery. This graft was patent in the last follow-up examination, five months following surgery. The last patient in the unilateral bypass group presented the only instance of rupture in our experience with autologous venous grafts. This occurred in a 75-year-old white man (Patient 18) who had a 38 cm. greater saphenous graft placed from the left common femoral to the popliteal artery. Postoperatively the graft functioned well, with a return of palpable pulsations in the dorsalis pedis and posterior tibial arteries. However, gross infection was noted in the midthigh incision approximately one week after operation. This incision was partially opened, and purulent drainage disappeared within one week. The graft continued to function. During the fifth postoperative week the patient experienced sudden pain in the lower thigh, and the following day a pulsating hematoma was evident. At exploration a 3 mm. longitudinal rent in the distal third of the graft was found. There was hematoma in the wound but no evidence of infection. In an attempt to preserve the graft, a 4 cm. segment of the contralateral greater saphenous vein was anastomosed to the proximal and distal ends after resection of the ruptured segment. This functioned well for five days, at which time rupture of the secondary graft occurred, necessitating ligation of the major graft. It would appear that infection was responsible for the initial and secondary rupture of these venous grafts.

We feel it important to emphasize that in the case of the last patient, in which the graft had to be ligated, as well as in the three bypass grafts that thrombosed, the vascular supply to the extremity was not made worse by the operative procedures.

Comment

Table 5 indicates that the autologous venous graft has functioned satisfactorily in all instances where the distal arterial tree has been patent (Table 5). This includes five cases of arterial injury, six cases of aneurysm or arteriovenous fistula, and one instance in which tumor surgery necessitated resection of the femoral artery. There was no evidence of aneurysmal dilatation in this graft at the time of hemipelvectomy, 14 months after its insertion. There has been no thrombosis, rupture, or clinical evidence of aneurysm formation in these cases, in which the longest follow-up has been seven years.

TABLE 5.—*Clinical Course of Twenty-One Autologous Venous Grafts Introduced into the Peripheral Arterial System*

	No. of Grafts	Patent Grafts	Thrombosed Grafts	Ruptured Grafts	Per Cent Successful Grafts
Arterial trauma	5	5	0	0	100
Arterial aneurysms and A-V fistula	6	6	0	0	100
Resection of artery for tumor	1	1	0	0	100
Obliterative arterial disease					
Direct interposition	1	0	1	0	0
Bypass insertion	8	4	3	1	50
Total	21	16	4	1	76

Failure of the autologous venous graft occurred only following its use for segmental arterial occlusion. When we used autologous venous grafts in the periphery, as recently described by Linton [1] and Crawford and co-workers,[2] thrombosis occurred in three cases and rupture in one case. The recent report of Hoye and Warren [3] regarding the incidence of immediate and late thrombosis of arterial homografts and autol-

ogous venous grafts should be cited. These authors reported closure in 12 of 16 arterial homografts and in 8 of 13 venous autografts inserted into the arterial system of the lower extremity, utilizing end-to-end anastomoses and also the bypassing technique.

The most frequently voiced criticism of autologous venous grafts is that they are more prone to secondary thrombosis and aneurysm formation than are arterial homografts or plastic prostheses. We think it important, as emphasized by Dye and coworkers,[4] to differentiate between the introduction of a graft of any type into an essentially normal arterial tree and into a tree that is the seat of diffuse disease and multiple areas of segmental occlusion. Obviously the percentage of patent grafts under the former set of circumstances will be higher, regardless of the type of graft that is used. When this yardstick is applied to the problem and blood vessel grafts in a normal arterial tree are considered, we are disinclined to agree that the incidence of thrombosis is higher with venous autografts than with other types of vascular graft. Murray[5] has reported upon the long-term behavior of venous grafts and has cited one patient in whom a patent graft inserted for trauma has been followed for 15 years without evidence of aneurysm formation or calcification. Jahnke and Seeley,[6] in their report on the treatment of vascular injuries in the Korean War, state a definite preference for autologous venous grafts over homologous arterial grafts in immediate reconstructive procedures upon the peripheral arteries. Seeley,[7] reporting upon the use of autogenous veins in the reconstruction of arterial continuity following surgery for aneurysm and arteriovenous fistula, has found autogenous veins "entirely satisfactory."

Summary

Twenty-one autologous venous grafts have been inserted into the peripheral arterial tree. The indications for the procedure included five cases of arterial injury, six cases of arterial aneurysm or arteriovenous fistula, and one instance in which the resection of a malignancy of the thigh necessitated the sacrifice of the common and superficial femoral arteries. These 12 grafts have remained patent, and the longest follow-up interval has been seven years. No aneurysm of any of the grafts has been noted. The use of autologous venous grafts in the treatment of segmental obliterative arterial disease has been less satisfactory. Direct interposition of a venous graft has failed in one case, and the utilization of the bypass principle has been successful in only four of eight cases. These patients have been followed for only a brief period, and it is possible that late thrombosis may further reduce the number of successful cases.

The present series would indicate that autologous venous grafts function well when introduced into a peripheral arterial system where there is patency of the distal arterial tree and there is no interference with the arterial run-off. It would appear that this graft, by reason of its universal availability, its uncontaminated state, and its freedom from potential antigenicity, represents the most satisfactory graft for the restoration of peripheral arterial continuity. The failure of the autologous venous graft when used in segmental obliterative disease of the peripheral arteries is thought to result more from the disease process itself than from any inherent deficiencies in the graft.

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DISCUSSION

ON PAPERS BY DRS. LE FEVRE, HUMPHRIES, AND DE WOLFE AND LORD AND STONE.

DR. WINDSOR, Los Angeles: There is one member of our audience, Dr. Fontaine, who I am sure has had considerable experience in this line. I wonder if he would care to make any comments?

DR. FONTAINE, Strasbourg: We have been using grafts for occlusive disease since 1945. Our experience has been the same as the colleague who spoke just before me. For arterial injury and aneurysm the results are very good, even as long as five, seven, and nine years after the operation.

We have had only 2 cases from about 60 where we have had trouble after use of a graft for aneurysm. One had sinus a couple of weeks after the operation and the graft was removed as an emergency for hemorrhage, and one other was operated on and the graft removed.

The result for occlusive segmental obliteration after a term of from three to seven years is not so good as for aneurysm and for injury. In this particular field of segmental occlusion by arteriosclerotic and Bürger's obliteration, if we had taken into consideration present knowledge, we would not operate on some of the earlier cases today.

We have about one-third who showed obliteration pretty soon after the operation, and another 25% who showed obliteration a couple of months after the operation, and into the next two years. After more than three years up to nine years, we have 174 grafts done for segmental occlusion by sclerotic and Bürger's, and 37% of the cases were certainly patent. These are the results.

Even in the cases of those who had occlusion in a space of between a couple of weeks and two years after the operation, very many have had an excellent clinical result, but there is evidence that the graft was occluded.

There is no doubt about the difference in the two special fields of cases indicated for graft: on the one side, arterial aneurysm and traumatic cases, and on the other side, segmental occlusion.

When you have segmental occlusion, the artery is diseased above and below, and this makes a difference, and you don't do anything about the initial disease. We treat the complication, and the disease process continues. The result will always be not as good in spontaneous occlusion as it will be for aneurysm and traumatic occlusion.

I like very much the autologous venous graft for the iliac artery, but for the aorta I think the best thing is an aortic homograft, especially deep freeze homograft. We did not find any very significant functional difference between the autologous venous graft and the deep freeze homografts.

DR. D. EMERICK SZILAGYI, Detroit: I should like to present the findings of a survey of the results of 120 grafting procedures for occlusive arterial disease followed for up to 33 months. The primary purpose of the study was the investigation of the causes of late failures, that is, the causes leading to loss of function of previously open grafts.

A large proportion (over 40%) of the operations was performed for far-advanced forms of the disease. Almost all the arterial substitutes used were homografts sterilized with β-propiolactone, and about three-fourths of these were fresh-preserved. About 60% of the procedures were of the type utilizing end-to-end anastomoses, while in the remainder at least the distal anastomosis was of the end-to-side variety.

The accompanying Table gives the summary of the results.

The figures for late results are cumulative. Patency of the grafts was angiographically proved in all but two cases.

It is seen that 23, or 19.1%, of the grafts became occluded immediately after operation and that during the subsequent 33 months 21 more grafts lost their function, thus giving an over-all rate of late success of 63.3%. The results with femoropopliteal grafting were by far the poorest.

From evidence obtained by angiography, secondary exploration, and exploration with biopsy in the 21 cases of late failures, the commonest cause leading to late closure of previously patent grafts was the extent and severity of the preexisting arterial disease either through postoperative progression or owing to incomplete excision. Although technical variations in the type of graft placement and technique of anastomosis did not seem to be the primary cause of any of the failures, the technical superiority of procedures utilizing end-to-side distal anastomosis was confirmed, and collateral evidence suggested that this type of anastomosis may delay narrowing near the suture line. Occlusions, wherein the cause was traced to intrinsic defects in the grafts were uncommon, but in a considerable number of cases (17%) progressive angiographic changes were noted in the arterial substitutes that may in time lead to occlusion.

DR. LINTON, Brookline, Mass.: I have been very interested in both of these papers and wish to

Results in 120 Grafting Procedures

	Operations, No.	Early Results		Late Results	
		Open	Closed	Open	Closed
Aortoiliac	49	42	7	39	10
Femoropopliteal	71	55	16	37	34
Total	120	97	23 (19.1%)	76	44 (36.7%)

congratulate the essayists on their presentations. Naturally, we are all interested in what our end-results are going to be, and would that we could look into a crystal ball to see what type of operation we will be doing in this field of surgery 10 years from now.

We have had better success in our cases than those reported here today. For example, in 94 cases of bypass homografts performed in the past two years on patients with segmental occlusion of the femoral artery, only 6, or 6%, have occluded to date and 88, or 94%, are still functioning.

In my opinion, there is no question that autologous saphenous vein grafts are the best that we have, but, unfortunately, they are not available in sufficient lengths or large enough caliber to use in the vast majority of cases.

I have developed a method, however, utilizing short segments of venous autografts, which I think is worth mentioning here. It consists in the utilization of a venous autograft by anastomosing it to an arterial homograft to obtain sufficient length to bypass long segments of arterial occlusive disease. The vein is anastomosed to the distal host artery because it is of finer texture and therefore can be sutured to poor quality arteries than can the thicker-walled arterial homograft.

To demonstrate what has been possible by this method, I will show you a few slides. The first is a femoral arteriogram in an elderly woman with severe obliterative disease, one which I did not think I could put a graft in but nevertheless thought it was worth an attempt, after getting the patient's permission to amputate her leg if it were not possible. A 6 cm. piece of saphenous vein autograft was used as the distal portion of the graft. It was put in by the end-to-side technique of anastomosis. The proximal part of the graft was the arterial homograft and was also anastomosed to the common femoral artery of the host by the end-to-side method. The operative procedure was performed in February, 1955, and the graft is still patent. This slide illustrates the appearance of the affected limb before the operation, and the next one, the appearance of it at this time, and, believe it or not, there is a faint dorsalis pedis pulsation on the dorsum of her foot.

The next case demonstrates the success of this method even utilizing the end-to-end technique of anastomosis. In this patient, a homologous arterial graft was implanted from the bifurcation of the aorta down to above the popliteal artery and anastomosed there to a 10 cm. section of autologous saphenous vein, with a distal end-to-end anastomosis to the popliteal artery of the host. This operation was performed in April, 1953, and the graft is still patent and functioning with good pulsations in the foot.

This slide shows the venous autograft, and the next one, the arterial homograft. The popliteal artery shown with the end-to-end anastomosis with the venous autograft.

The next slide shows the use of arterial homograft in very severe obliterative disease in a man in whom we inserted an aortic bifurcation homograft, with anastomoses to his external iliac and common femoral arteries, and bypass arterial homografts down both legs to his popliteal arteries. Such extensive grafting procedures have been possible utilizing the long arterial homografts implanted with the end-to-side technique of anastomosis.

DR. COOLEY, Houston: Our experience with aortic and arterial grafting includes about 700 cases, of which 470 were aortic grafts and 230 were grafts of peripheral arteries or major vessels. For the most part these grafts have been homologous arteries, but in some 50 cases various synthetic materials were used. In large-caliber vessels, such as the aorta and iliac arteries, I believe the synthetics are as good as the homografts, but in small-caliber vessels such as the femoral arteries the homografts may be superior.

The ultimate fate of all the arterial replacements will occupy our interest for years to come. We have already collected a number of specimens of aortic homograft from patients dying as much as 30 months after operation, usually from coronary occlusion. It has been surprising how well preserved the elastic coats of these vessels are at the end of this period. The degree of fragmentation is relatively slight, and gross characteristics of the graft are well preserved too. These findings are being reported in detail, and I hope that others will be encouraged to report their experience too.

DR. DETERLING, New York: I would just like to make a few broad comments on behalf of Drs. Blakemore, McAllister, and myself, whose combined experience amounts to over 200 cases. We have observed very much the same trend as demon-

strated in the papers today, in that the result with aneurysm, insofar as patency is concerned, is uniformly good. Our worst results, insofar as functional success is concerned, are in cases with peripheral thrombotic disease.

In my opinion, the autologous vein is not the best type of graft. When used as short replacements for peripheral aneurysms, I don't deny that they are all right, particularly in the popliteal artery. However, I have observed a high percentage of thrombosis of long vein grafts used in occlusive diseases of the extremities, which is in contrast to my experience with arterial homografts. My best results so far have been with the homograft implanted as a bypass. I believe that the bypass is superior to end-to-end method in treating thrombotic disease. In a personal group of over 25 cases followed up to 15 months, 18 have pedal pulses. Of the remainder, three patients have warm pink feet but no palpable pedal pulses. Two had failure of the graft from the time of operation, and in these reoperation and use of a longer graft resulted in success. There have been three late thromboses. In one case the occlusion occurred distal to the graft. I believe arteriography is indicated in late failures. We have had in excess of 90 cases with synthetic grafts, and, as you might expect, the worst results were in patients with peripheral thrombotic disease.

Like everyone else, we have learned to exclude some cases in which arteriography, as Dr. Humphries pointed out, has demonstrated inadequate arteries distal to the segmental occlusion. With poor peripheral vessels, particularly in the tibial region, one has little chance of lasting success, no matter what kind of graft material is employed.

DR. LORD, New York: First I would like to thank the discussers for their comments, and I cannot help but take this opportunity, probably the first and last time it ever has (or will) occurred to me, to out-do Dr. Cooley.

Compared with the 700 grafts of theirs, we have probably had 55, but we do have a follow-up, most unfortunately, of a patient who had a brain operation some 1034 days after the insertion of his graft for an abdominal aortic aneurysm.

I have four slides which we will run through. The black arrows indicate the sites of the anastomosis of the graft. The two white arrows point to areas of new small aneurysms, one in the aorta above the graft and the other in the distal aorta.

This slide shows the opened specimen and the graft. Between the two black arrows there was a thin fibrin layer that did not interfere with pulses which were present in his feet to the time of death.

Microscopically, the only difference is that the graft is slightly less cellular than the host's aorta. However, after almost three years, it looks well. This is also true of the media.

Surgical Management of Cervical Carotid Aneurysms

JESSE E. THOMPSON, M.D., and DALE J. AUSTIN, M.D., Dallas, Texas

Aneurysms of the carotid artery in the neck are relatively uncommon, being less frequent in occurrence than aneurysms of the aorta or the popliteal artery. The trunk of the common carotid and its bifurcation are the sites most frequently involved, while aneurysms of the internal and external carotid branches are quite rare.[1,2] Aneurysms of the intracranial portion of the internal carotid are rather common but are not the subject of this paper. Carotid aneurysms, like other aneurysms, are either traumatic or spontaneous, the etiology of the latter group being usually arteriosclerosis or syphilis.

The management of cervical carotid aneurysms in the past has been variable and not entirely satisfactory, as occasional reports in the literature show. The exact surgical treatment has depended upon the location of the aneurysm, its size, the severity of symptoms, and the general state of the patient. In all cases, however, the basic problem has been the possibility of cerebral complications which can follow ligation of the common or internal carotid in the neck. Multiple measures designed to test or to improve cerebral circulation have been used over the years, none of which has been uniformly satisfactory or accurate. The hazards of carotid ligation have been weighed against the hazards presented by the aneurysm, and no stereotyped surgical approach has been possible. With the advent of recent technical advances in vascular surgery, specifically the use of homografts and vascular shunts, it would seem that many of the hazards feared by the older surgeons could be lessened or even eliminated in large part. Each case must still be individualized, but it is to be expected that with increasing experience most of the cervical carotid lesions can be managed satisfactorily in a definitive manner.

We have had the opportunity to treat six patients with aneurysms of the cervical portion of the carotid artery. There were four at the bifurcation of the common carotid, one of the left internal carotid, and one in the trunk of the right common carotid, which was treated surgically but recurred and had to be reoperated upon. Four patients were women, and two were men. Their ages ranged from 42 to 77, with an average of 55 years. All the aneurysms were spontaneous with the exception of one, in which there was a possible relationship to trauma. These cases are grouped below according to the method of surgical management employed.

Report of Cases

Wrapping of aneurysm with fascia lata (or cellophane)

CASE 1.—A 42-year-old woman complained of soreness in the left side of the neck and pain in the left ear. Physical examination revealed a 2.5 cm. pulsating mass in the left side of the neck at the level of the hyoid bone. At operation, on March 20, 1954, an aneurysm of the carotid bifurcation was found (Fig. 1A). It was freed up and wrapped with a strip of fascia lata. The wrapping began around the common carotid 1 cm. proximal to the bulb, continued around the aneurysm, and included the proximal 1 cm. of the internal and external carotids (Fig. 1B). Swelling in the area from reaction produced by the fascia presisted several weeks but then gradually subsided. When last examined, two years after operation, the patient was asymptomatic and presented a carotid artery of normal size and pulsation. It is of interest that this

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Fig. 1A.—Spontaneous aneurysm at the bifurcation of the common carotid artery. This lesion may be very symptomatic. Pain in and behind the ear is common; c. c., common carotid artery; i. c., internal carotid artery; e. c., external carotid artery.

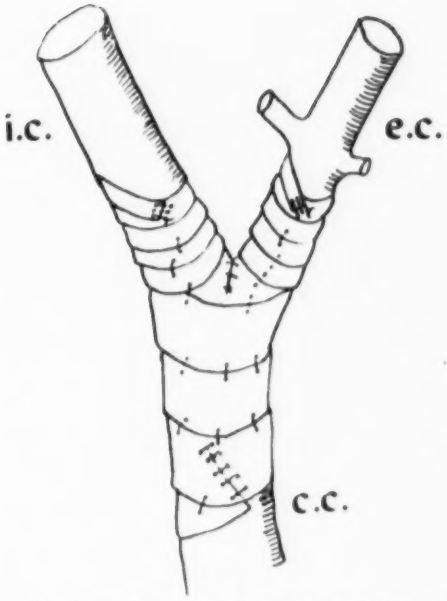

Fig. 1B.—Diagram of the method of treating aneurysms at the carotid bifurcation by wrapping with a strip of fascia lata from the thigh. This produces a dense mass of connective tissue which prevents the artery from expanding. Four patients have been cured to date.

patient's father had died some years before from rupture of a carotid aneurysm in the neck.

CASE 2.—A 50-year-old woman complained of a lump in the right side of the neck of three years' duration, with intermittent pain and tenderness in the mass and pain anterior to the right ear. Physical examination revealed a pulsating mass in the right side of the neck at the level of the carotid bifurcation. At operation, on July 19, 1954, a 2.0 cm. aneurysm of the carotid bifurcation was found. It was wrapped with fascia lata from the thigh. Twenty-one months after operation she was asymptomatic and the abnormal pulsating mass was no longer present.

CASE 3.—A 51-year-old woman complained of soreness in the left side of the neck of three months' duration. Physical examination revealed a 3×2 cm. pulsating mass in the left side of the neck at the level of the hyoid bone. At operation, on Sept. 12, 1955, an aneurysm of the carotid bifurcation was found, being twice the normal diameter of the artery. It was wrapped with fascia lata. She has been well and asymptomatic to date.

CASE 4.—A 61-year-old man complained of a tender lump in the right side of the neck of five months' duration. Physical examination revealed a pulsating mass at the level of the hyoid bone. At operation, on Aug. 6, 1950, an aneurysm of the carotid bifurcation was found, three times the normal diameter of the vessel. It was wrapped with cellophane. The mass shrank to a normal size, and the patient became free of pain. He has continued well for 5 years and 10 months.

Comment.—Relatively small aneurysms of the carotid bifurcation may be very symptomatic. Since their extirpation entails either ligation of the common, internal, and external carotids or anastomosis of the common and internal carotids with or without an arterial graft, it has been felt that the risk of cerebral complications has been too great for these four particular lesions. Hence, wrapping has been done, the results of which have been most encouraging. Symptoms have been relieved, and the reaction produced by the fascia has caused the enlarged vessels to be shrunken to a normal or near-normal size. Since the risk of wrapping is nil, and the results appear to

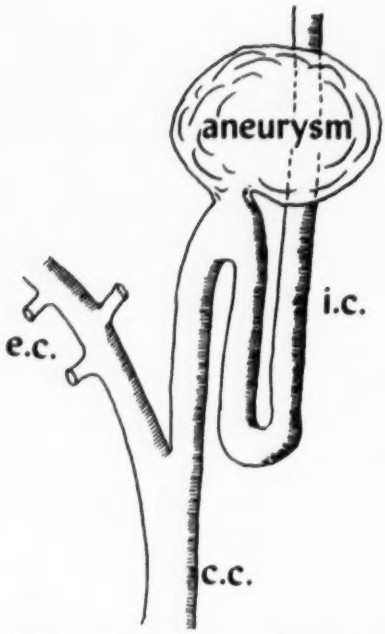

Fig. 2A.—Arteriosclerotic saccular aneurysm on a tortuous internal carotid artery in a 77-year-old woman who complained of a pulsating cervical mass and pruritis in the external auditory canal.

be curative, this conservative method of treatment seems justified and suitable for these aneurysms of the carotid bifurcation.

Resection of aneurysm with arteriorrhaphy and fascia lata wrapping

CASE 5.—A 77-year-old woman had noticed a bulge in the left side of her neck for five years. For one year she had had pruritis of the left ear. Physical examination revealed a 4 cm. pulsating mass high in the left side of the neck. At operation, on May 25, 1955, an arteriosclerotic saccular aneurysm was found arising from a tortuous S-shaped internal carotid artery by an opening 0.5 cm. in diameter (Fig. 2A). The aneurysm was densely adherent to all surrounding structures. It was dissected free, a Potts clamp was placed across its neck, and it was removed. The artery wall was then closed with 00000 nonabsorbable surgical (silk) sutures, without interference with internal carotid blood flow. That portion of the vessel containing the arteriorrhaphy wound was then wrapped with fascia lata (Fig. 2B). When last checked, 13 months after operation, the patient was asymptomatic except for slight hoarseness and no abnormal mass was palpable.

Comment.—An occasional saccular carotid aneurysm occurs which lends itself to ideal treatment; namely, resection through the neck of the sac with suture of the vessel wall without interruption of carotid blood flow. This is a curative method. In the case reported the sclerotic vessel wall was reinforced with a wrapping of fascia lata.

Resection of aneurysm with arteriorrhaphy and fascia lata wrapping followed by recurrence treated by aneurysmectomy and homograft replacement

CASE 6.—A 48-year-old man complained of a mass in the right side of the neck of three weeks' known duration. Six years previously, in an automobile accident, he sustained, among other injuries, a massive hematoma in his neck, which gradually subsided. Physical examination revealed a large pulsating mass in the right side of the neck just above the clavicle. At operation, on Jan. 19, 1956, a transverse incision was made low in the neck and the inner third of the clavicle was resected. A 9×6 cm. aneurysm was found involving the common carotid to within 2 cm. of its bifurcation and 1.5 cm. of the distal innominate artery (Fig. 3A). The mass was disected free of adjacent structures, and a De Bakey clamp was placed across its base parallel to the long axis of the common carotid. The aneurysm was resected, and arteriorrhaphy was done with 0000 silk, preserving carotid flow. The carotid and distal innominate arteries were then wrapped with a sheet

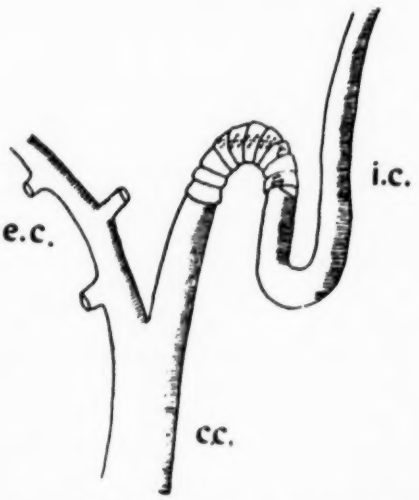

Fig. 2B.—Diagram of the method of treatment of the aneurysm shown in Figure 2A by resection, arteriorrhaphy, and fascia lata reinforcement, with preservation of carotid blood flow. Patient was cured.

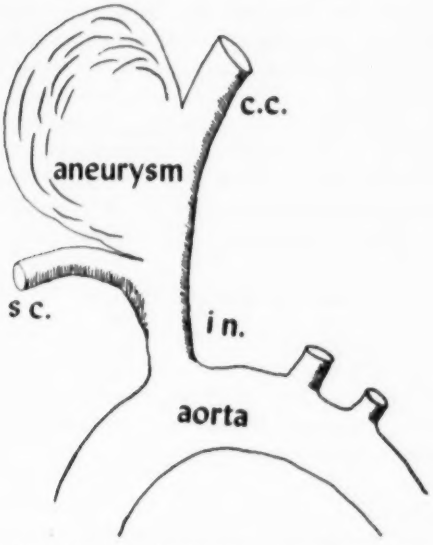

Fig. 3A.—Arteriosclerotic aneurysm of common carotid artery in a 48-year-old man with a history of severe cervical trauma six years previously. The distal portion of the innominate artery was also dilated; in., innominate artery; sc., subclavian artery.

of fascia lata (Fig. 3B). The pathologist's report was arteriosclerotic aneurysm.

The patient did well until May 8, 1956, when he noted the recurrence of a pulsating mass just above the right clavicle. Examination revealed a large pulsating mass, 6×6 cm., at the site of the previous dissection. Reoperation was done on May 14, 1956. With use of local anesthesia, the common carotid was exposed above the mass, and a bulldog clamp was placed on it for 25 minutes. The patient experienced no untoward signs or symptoms; so the clamp was removed and he was anesthetized. A combined cervicothoracic approach was then employed. The sternum was split, and both third intercostal spaces were incised. Excellent exposure was obtained, and proximal control of the innominate artery was effected. Dissection of the aneurysmal mass was extremely difficult. It was obvious that the posterior wall of the false sac could not be safely dissected off the brachial plexus or subclavian vessels. Hence the innominate and carotid arteries were ligated flush with the aneurysm; clamps were placed proximally and distally, and the vessels were divided. A 7 cm. frozen arterial homograft was then sutured end-to-end between the innominate and the common carotid arteries, with use of 0000 arterial silk. Carotid flow was reestablished after 50 minutes of occlusion. The anterior wall of the aneurysmal sac was then resected. There was a vigorous retrograde pulsatile flow of blood into the aneurysm from the subclavian orifice, which was closed by suture. As much of the remainder of the sac as could safely be removed was excised (Fig. 3C). The aneurysm had recurred because the sutures had torn out of the sclerotic carotid wall and the fascia lata had failed to protect the suture line from this catastrophe.

At this point in the operation it was noted that considerable oozing was occurring from all areas of the wound, and it was feared that the patient had had a blood transfusion reaction. Calcium gluconate, vitamin K, and protamine were given, without effect. Wound closure was carried out, but the oozing continued. The graft was functioning well, and the patient's condition was otherwise satisfactory. He had received 8000 cc. of whole blood. He was returned to his room and began to regain consciousness. There was no evidence of paralysis of the face, hand, arm, or leg or aphasia, and it was felt that the innominate-carotid graft had been placed without any cerebral complications.

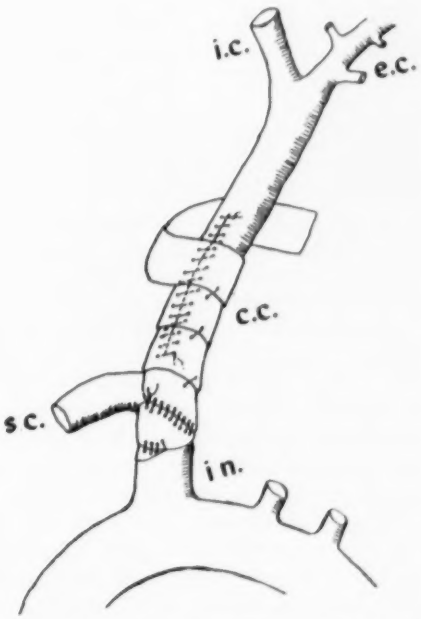

Fig. 3B.—Diagram showing first method of treatment of aneurysm depicted in Figure 3A, by resection, arteriorrhaphy, and wrapping the carotid and innominate arteries with a sheet of fascia lata. This friable artery wall eventually gave way, and the aneurysm recurred, the fascia lata being unable to prevent this catastrophe.

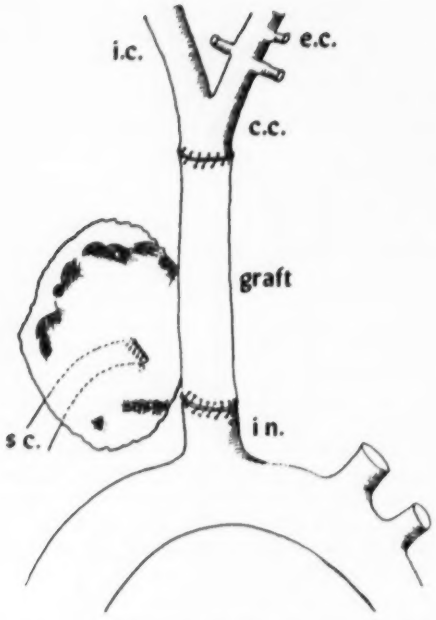

Fig. 3C.—Diagram showing the second procedure carried out on the recurrent aneurysm of Figure 3A. A frozen arterial homograft was sutured between the innominate and the common carotid arteries, with restoration of carotid blood flow. Most of the false aneurysmal sac was resected, and the orifice of the subclavian artery was closed by suture from within the sac. A portion of the posterior aneurysmal wall overlying the brachial plexus was left in situ.

Oozing continued, and the patient was given more transfusions. He appeared to be doing satisfactorily when he died suddenly, on the morning of the first postoperative day.

Comment.—This case represents a failure of arteriorrhaphy and fascia lata wrapping for a large carotid aneurysm with friable arteriosclerotic walls. It could have been best treated by removal and arterial grafting in the first instance rather than after it recurred. The fatal outcome would probably not have occurred under these circumstances. As the patient had been tested for carotid occlusion prior to general anesthesia, it appeared safe to occlude the innominate and the common carotid arteries for the length of time required to insert the graft. The patient exhibited no signs or symptoms of paralysis after operation and died most probably as a result of a transfusion reaction. In cases of large fusiform carotid aneurysms or those saccular ones with wide necks, it is suggested that aneurysmectomy with graft replacement to restore carotid flow, following a preliminary carotid occlusion tolerance test, is the procedure of choice. Adequate exposure is necessary and may require resection of the clavicle, median sternotomy, and intercostal incisions.

Review of the Literature

Carotid Ligation.—The definitive management of cervical carotid aneurysms, as with other lesions involving the carotid arteries, has been intimately associated with the hazards accompanying ligation of the carotid artery, either the common or its internal branch. Ligation of the external carotid poses no problem. One cannot with impunity interrupt carotid flow, since experience over many years has shown that hemiplegia or death will follow in a certain number of cases. Ambroise Paré published the first account of operative ligation of the common carotid in 1552. His patient developed an aphasia and a left monoplegia.[3] The incidence of cerebral complications varies considerably in the series reported, because of the many factors involved. Pilcher and Thuss [4] surveyed the literature in detail and concluded that occlusion of a common carotid artery will be followed by definite symptoms referable to the brain in probably 20% to 30% of cases. Homans [5] reported a fatal case and in a review likewise concluded that carotid ligation is hazardous. Watson and Silverstone [3] have given an historical survey of the subject and have reported a mortality of 50% in a series of their own patients having the common carotid ligated for cancer of the head and neck. Matas [6] reported a 7% mortality from common carotid ligation and stated that three additional patients were rescued from coma by the use of removable metal bands. Lahey and Warren [7] believed that carotid ligation carried too prohibitive a morbidity and mortality rate to be justified in surgery of carotid body tumors. Two recent reports

have given more favorable results from carotid ligation. Thus, Rogers [8] reported a series of 19 ligations with no complications. All of these patients had undergone a period of temporary occlusion as a test procedure. Steelman, Hayes, and Rizzoli [9] reported 14 cases of carotid ligation with no deaths and 1 hemiplegia, the latter resulting from primary internal carotid ligation.

The procedures which have been used in an attempt to prevent cerebral complications following carotid ligations and the reasons underlying each of them have been discussed in detail by Dorrance.[10] Some of these have been tests of adequate cerebral flow, whereas others have been measures designed to increase cerebral collateral circulation. The Matas test has been used extensively. Here the carotid is compressed manually and the patient's tolerance is noted. A false test is sometimes obtained because of a sensitive carotid sinus. At other times the artery is not completely compressed and a false sense of security results. Again, a hemiplegia may result several days after carotid ligation when the tolerance test was satisfactory. An actual operative exposure of the carotid under local anesthesia with complete temporary occlusion for 20 to 30 minutes has been used by some with success.[8]

Dandy [11] used metal bands and, particularly, fascial bands to occlude the carotid partially and so promote cerebral collateral circulation. He reported success with fascia lata ligation in 30 cases for the treatment of intracranial carotid aneurysms.

Another method attempting to maintain and promote an adequate cerebral circulation has been ligation of the carotid in stages. Thus, the common carotid is first ligated and then the internal carotid, days to weeks later.[9,10] The rationale of this operation is that after common carotid ligation blood will flow from the external to the internal carotid and so to the brain. However, the data of Sweet, Sarnoff, and Bakay,[12] from direct intraarterial manometric studies, do not corroborate this clinical impression. Nevertheless, they too conclude that when in doubt and without the pressure-measuring device it is probably safer to ligate the common carotid than the internal.

Reasoning along these same lines, Conley and Pack [13] have anastomosed the external to the internal carotid artery in four elderly patients in whom the carotid bulb had to be sacrificed in the removal of tumors. There were no complications and no deaths.

Shea [14,15] has recently had the opportunity in two cases to anastomose directly the common to the internal carotid after resection of the carotid bifurcation and so restore carotid flow. Both of these operations were successful.

Denman [16] has resected thrombosed segments of carotid arteries and restored continuity by means of a homograft between the common and internal carotids on the left and between the common and external carotids on the right side of the same patient.

Thus, the technical problems surrounding lesions involving the cervical portion of the carotid arteries may best be surmounted either by direct anastomosis or by homograft restoration of arterial flow. This of course has no bearing on the hazards attending carotid ligation for the management of intracranial aneurysms, but it does have implications for the surgical treatment of cervical carotid aneurysms, carotid body tumors, arteriovenous fistulae, and cancer of the neck. The tolerance tests which have been previously employed find great usefulness in allowing one to determine the length of time a carotid may be safely occluded, during which time an anastomosis or a graft may be done.

Surgical Management.—Surgical management of cervical carotid aneurysms has varied considerably in reported cases, as have the results of such treatment. Accurate statistical evaluation is impossible because of the infrequency of the lesion. Methods of treatment have been reviewed by Matas,[2] Reid,[1] and, more recently, Kirby, Johnson, and Donald.[17] Operative methods have included (1) proximal ligation, (2) distal ligation, (3) proximal and distal ligation with incision, (4) extirpation, (5) gradual

obliteration with metallic or fascial bands, (6) endoaneurysmorrhaphy, and (7) resection with anastomosis.

Proximal ligation has been the most commonly employed method.[18] Sir Astley Cooper is credited with having done the first common carotid ligation for aneurysm in 1805.[3] Results of this operation have been poor, however. Reid,[1] in reviewing the Johns Hopkins cases in 1926, reported only 6 cases cured among 13 treated.

Extirpation with carotid ligation has given curative results when not accompanied by the cerebral complications attending such ligation. Shea[15] has recently reported a case in which the aneurysm was excised and carotid blood flow restored by end-to-end anastomosis of the common and internal carotid arteries. Such a favorable circumstance arises infrequently, however. Resection with arteriorrhaphy has been employed by Bahnson[19] and by Cooley and De Bakey[20] for resection of aneurysms of the thoracic aorta and is applicable to certain carotid aneurysms. Mahorner and Spencer[21] have reported the establishment of a shunt graft from the innominate to the common carotid without interruption of carotid flow prior to resection of an aneurysm involving the innominate, carotid, and subclavian arteries. Such shunts have also been reported by others[22] in resection of aneurysms of the arch of the aorta.

Fascia lata has been employed successfully for carotid ligation[11] and for wrapping of aneurysms in other areas.[23] A dense mass of connective tissue forms around the fascia and prevents the artery from reexpanding even if the fascia disintegrates.

Surgical Approach.—For aneurysms of the internal carotid and the carotid bifurcation, transverse or vertical incisions in the neck give adequate exposure. For large aneurysms of the common trunk and for those that also involve the innominate artery, a wider exposure is needed. Resection of the inner third of the clavicle, as outlined by Elkin and Cooper,[24] greatly improves the exposure and may be all that is necessary. When the superior anterior mediastinum must be exposed, then the sternum can be split and the third intercostal space incised, as described by Elkin[25] and Shumacker.[26] At times a combined cervicothoracic approach is necessary in order to effect proximal and distal control of the lesion.[27] Gage[28] has described a case of common carotid-jugular arteriovenous aneurysm in which a transpleural approach was necessary to control the proximal arterial supply. One cannot overemphasize the necessity of adequate exposure in dealing with large low-lying carotid aneurysms.

Comment

There is general agreement that ligation of the common or internal carotid artery carries an unpredictable but definite hazard of hemiplegia or even death. This fact is the basic one determining therapy of carotid aneurysms. In small aneurysms of the carotid bifurcation in which the likelihood of rupture appears small, radical therapy in the form of excision has not appeared to be justified. These lesions, however, are often symptomatic, may progress, and hence require therapy. Pain in the ear is a frequent complaint, probably mediated over the glossopharyngeal nerve. Wrapping of these lesions with fascia lata carries no risk and appears to be effective in relieving symptoms, reducing the size of the aneurysms, and preventing progression, as demonstrated by the cases reported here. With vascular grafts now readily available, these may be resected and grafted, but the risk of cerebral damage, though small, will still be present. If, as time goes on, some of our bifurcation aneurysms which have been wrapped recur or enlarge, then resection and grafting will have to be done.

The larger aneurysms of the common and internal carotids should be treated by resection if a cure is to be obtained. Ligation of the vessels followed by excision is curative but carries a definite risk. Saccular aneurysms with a narrow neck may be resected and arteriorrhaphy carried out. The sclerotic vessel wall may be reinforced by

fascia lata wrapping. Arteriorrhaphy with fascia lata wrapping for large aneurysms is probably not wise, because of the friable arterial wall and the technical difficulties involved. In an occasional case circulation can be restored by direct end-to-end anastomosis, but in the majority grafting will probably be necessary. Much time can be saved if the graft is first inserted, either end-to-end or as a shunt graft, and that portion of the aneurysm which can be safely removed is then resected, any vessels entering the sac being treated by endoaneurysmorrhaphy. This is a well-established principle in aneurysm surgery and applies particularly well in the neck, where dissection may be extremely difficult and dangerous.

Though not infallible, the carotid occlusion tolerance test will help one decide whether the patient can stand carotid occlusion. The judicious use of this test combined with aneurysmectomy and arterial grafting should reduce the risk to a very low level and improve the results of therapy in carotid aneurysms.

Summary

The surgical management of carotid aneurysms in the neck is reviewed.

The hazards associated with the treatment of these aneurysms stem from the cerebral complications of carotid artery ligation.

A series of six patients with cervical carotid aneurysms is reported, three methods of treatment having been used:

(*a*) Four aneurysms of the carotid bifurcation were wrapped, three with fascia lata and one with cellophane, with relief of symptoms and curative results.

(*b*) A saccular aneurysm of the internal carotid was cured by resection and arteriorrhaphy with preservation of carotid flow.

(*c*) A large aneurysm of the common carotid was treated by aneurysmectomy and arterial grafting between the innominate and the common carotid arteries after a previous operation of resection, arteriorrhaphy, and fascia lata wrapping had failed. The patient died, with a functioning graft and with no evidence of cerebral complications.

Conclusions

It is recommended that small symptomatic aneurysms of the carotid bifurcation be treated by fascia lata wrapping.

Resection with restoration of carotid blood flow is the treatment recommended for other carotid aneurysms. This can be done by arteriorrhaphy, end-to-end anastomosis, or arterial grafting.

The carotid occlusion tolerance test is helpful in determining whether the patient can tolerate carotid occlusion long enough for a graft to be inserted.

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DISCUSSION

DR. DENTON A. COOLEY, Houston, Texas: Although there may be some doubt as to the future of hypothermia in cardiac surgery because of certain inherent limitations of the method, I believe that hypothermia has a definite place in protecting the central nervous system from ischemic damage during temporary interruption of circulation. It is surprising how few reports are available concerning the use of hypothermia to protect the brain during operation on the carotid artery. Several years ago Dr. Charles Robb, of London, had a case of arteriosclerotic occlusive disease involving the common and internal carotid arteries which was successfully treated under hypothermia. Recently, I operated on a patient with partial carotid occlusion and obtained an excellent result using a temporary by-pass shunt. Perhaps a combination of hypothermia plus shunts is the most effective means of protecting the brain during temporary carotid occlusion. I am sure that Dr. Thompson would agree that if the brain could be protected from ischemic damage that the most definitive method of treatment in fusiform aneurysms of the carotid is segmental arterial resection with graft replacement.

DR. ROSENBERG, Highland Park, N. J.: I would just like to show one slide which deals with the collagen weave patterns derived from different sources. On the left we see a thin fascia taken from a rabbit, stained with fuscin, and photographed from above, and it is evident that the fibers run in parallel fashion.

On the right is shown a purified collagen network of arterial wall origin, and here we see a much tighter weave, with a lot of crisscrossing of fibers, a pattern which might conceivably bear up better under the type of stresses found in the normal artery.

DR. JESSE E. THOMPSON, Dallas, Texas: I should like to thank the discussers. I think Dr. Cooley's suggestion of hypothermia is a very good one, especially for the large and difficult aneurysms such as our last patient exhibited. As brought out in the text, wrapping is not ideal therapy, but for patients who are not in dire circumstances we have hesitated to take any appreciable risk. Wrapping is certainly safe and in the cases reported has worked very well indeed to date. Time will tell whether we shall have to modify the procedure.

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The Use of Arterial Implants Prepared by Enzymatic Modification of Arterial Heterografts

II. The Physical Properties of the Elastica and Collagen Components of the Arterial Wall

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In a previous report [1] the use of enzyme-digested heterografts as arterial substitutes was described. Bovine arteries were stripped of most of their parenchymatous proteins by controlled enzyme action, leaving a tubular prosthesis composed mostly of collagen. These tubes were implanted into dogs as aortic substitutes with the hope that, with most of their immunologically reactive proteins removed, the implants would be better tolerated by the host while yet maintaining their effectiveness as arterial substitutes. Short-term observations (up to one year) seemed to corroborate this hypothesis.

Since the advent of arterial grafting and the blood vessel bank, the concept has gained acceptance that the integrity of the elastica greatly contributes to the strength of a graft. However, much of the older literature is opposed to that hypothesis. In 1939, by ingeniously calculating Young's modulus * for different weight applications, Krafka [2,3] was able to show that moduli obtained for the collagen component of the arterial wall were very high when compared with those found for the musculoelastic portion, i. e., the collagen presented several hundred times as much resistance to stretch. He also showed that sclerotic senile aorta had a much higher modulus than nonsclerotic aorta, owing to its higher collagen content.

In 1942, Hass [4,5] extracted aortic rings with formic acid and was able to obtain an intact purified network of elastic fibers. This, when fixed and stained, looked histologically like unaltered elastica and showed a high degree of extensibility on stress with return to almost its original dimensions when the stretching force was removed. However, Hass's elastica rings were weak, rupturing under stresses averaging 80 gm., while untreated rings took many pounds of pull before giving way.

Using data compiled from various sources, Burton [6] attempted an explanation of the roles of the elastica and collagen when visualized as separate entities and when operating in combination in the intact artery. He graphically showed the ability of the elastica to elongate under minimal load and the marked limitation to arterial expansion applied by the collagen after a point of permissible stretch had been reached.

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* Young's modulus is a coefficient of elasticity usually expressed as the number of dynes per square centimeter required to produce 100% elongation of the material under consideration. The higher the modulus, the greater the resistance to stretching forces. For further information see Krafka [2,3] and Burton.[6]

Method

"Collagen" Tubes.—Bovine carotid arteries, freshly removed from animals at slaughter, were trimmed of adherent tissue and thoroughly washed. The vessels were then subjected to digestion in a solution of 1% ficin (Merck) for three hours at

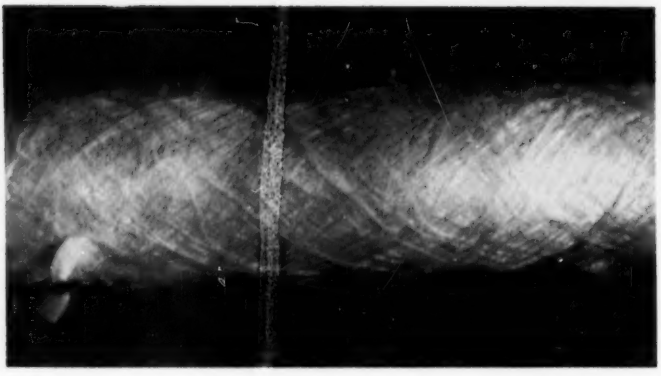


Fig. 1.—Gross appearance of collagen tube (ficin preparation) under low magnification. Note cross weave of adventitial fibers.

a temperature of 37 C, with use of a standard phosphate-citrate buffer to keep the pH at 5.0 or above. They were then washed in running water for one-half hour and further trimmed by hand to remove any superfluous matter. The resulting tubes, consisting mainly of collagen, were placed on glass rods and hardened by immersion in 1% formalin for 17 hours. After thorough washing, the preparations were stored in 50% alcohol. Formalin greatly improved the handling qualities of these tubes when they were employed as arterial grafts. (Fig. 1).

We accept the possibility that formalin treatment may influence or alter a number of the physical properties of collagen, and duplicate studies are being carried out to determine the behavior of less drastically treated preparations.

"Elastica" Preparations.—Hass[4,5] described a method for the preparation of a practically pure elastic network from arteries by extraction with formic acid. His preparations were reported to show the typical histological and staining characteristics of arterial elastica as well as physical properties of great extensibility and retractility. The following modification of his method was employed, with appropriate microscopic control.

The cleaned arterial rings were placed in alcohol for one-half hour at room temperature and then in ether for a similar period. Extraction in 92% formic acid was then carried out for 18 hours at 45 C. The resulting preparations were stored in 50% alcohol (Fig. 2).

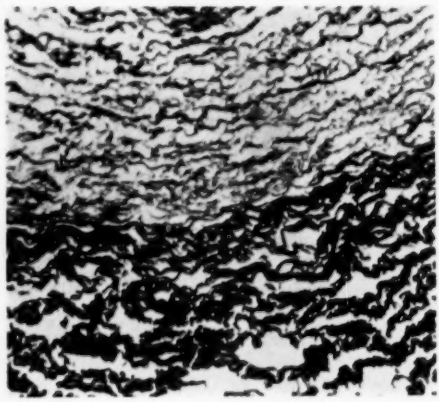
In another, less drastic, approach, an attempt was made merely to weaken and partially digest away the collagen and muscle by treatment with acetic acid and papain, without trying to achieve a "purified" type of preparation. Histological examination after treatment revealed considerable fragmented muscle and swollen altered collagen to be present. The elastica, however, appeared normal and, it was hoped, less altered by the relatively mild treatment.

In this technique, the stripped arterial rings were placed in 1.2% acetic acid for 2 hours at room temperature prior to being dropped in boiling water for 30 seconds. They were then treated with 0.5% papain for three hours at 37 C and pH 5.0. After washing, the rings were stored in 50% alcohol.

Controls.—These consisted of cleaned arterial segments stored in 50% alcohol.

Tensile Testing Procedure.—The arterial segments were cut into ½ in. (1.25 cm.) circular rings. The diameter of each was recorded, as was

Fig. 2.—Microphotograph showing purified elastica prepared after method of Hass, with use of formic acid extraction.



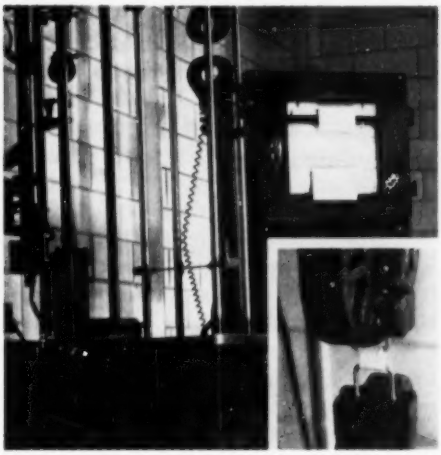


Fig. 3.—The Thwing-Albert Electrohydraulic Tensile Tester. Note the automatic graphic recorder. Insert shows arterial ring with U-shaped rods threaded through lumen of vessel and fixed in jaws of instrument.

the thickness of the wall at the thinnest point. Each ring was then tested by slipping it on to two U-shaped brass holders which were placed without stress in the jaws of the Thwing-Albert Electrohydraulic Tensile Tester. Operation of the apparatus resulted in the lower jaw moving at a prefixed speed, the upper jaw remaining stationary, until the vessel segment ruptured. An automatic graphic recorder plotted the breaking curve on calibrated paper. The breaking strength, tensile strength, and per cent elongation could be readily calculated from these tracings (Fig. 3).

Because of the considerable variability in results obtained from different carotid artery pairs, it was necessary to prepare rings taken in a standard manner from a given carotid, digesting the first ring in ficin and the next adjacent one in papain, with the third serving as control, and so forth. Complete patterns of data were therefore obtained from each carotid pair, rather than having a comparison of the vessels of one animal with those of another.

Histological examinations were made by the usual techniques, employing hematoxylin-and-eosin and Verhoeff's elastic tissue stains.

Results

Gross Observations.—The collagen tubes resulting from ficin digestion were elongated by enzyme treatment and became greater in diameter. This was easily seen grossly (Fig. 4), since the increment in both length and diameter was in the order of 35%. The change probably resulted from removal of the elastica with its spring-like action by the digestion process. The two types of elastica preparations both showed rubber-like characteristics, with retractability after extension. Both were relatively weak, the papain preparation being the stronger of the two and, as expected, more nearly resembling the intact artery in handling qualities. However, when an attempt was made to use papain preparations as actual aortic grafts in the dog, the sutures repeatedly cut through the implant, in one instance rendering grafting impossible. A second animal died 24 hours after grafting, with a slit-like longitudinal rupture in the central portion of the prosthesis.

Curves from Electrohydraulic Tester.—Figure 5 shows typical curves obtained from control, ficin-treated (collagen type), and

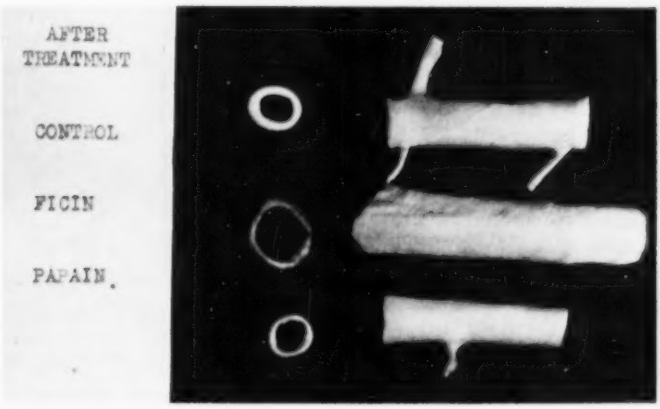


Fig. 4.—Note increase in diameter and length after ficin digestion.

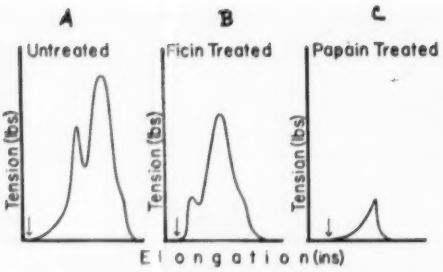


Fig. 5.—Stress curve of beef carotid arteries. Illustration of typical tension curves obtained with the Thwing-Albert Electrohydraulic Tensile Tester.

papain-treated (elastica type) preparations. Curves prepared from formic-acid-treated arteries gave tracings very similar to those from the papain group and are not illustrated.

The control tracing, or that for the intact artery, appears in Figure 5*A* and is similar to a composite of the collagen-type and the elastica-type tracings. There is an initial period of fairly rapid elongation under only slight increase in tension until a critical point is reached, after which, despite steady increase in the force applied, the elongation per unit stress is not great. The twin-peaked top of the curve represents several phases of dehiscence as the vessel wall frays out and finally gives way.

The collagen-type curve obtained from the ficin-treated artery (Fig. 5*B*) differs from the control tracing mainly in the lack of a significant initial phase of elongation. Instead, resistance to elongation develops very early in the tracing, and the curve rises steeply. From this point on, however, the tracing mimics that of the intact artery.

The elastica-type curve depicted here (Fig. 5*C*) mimics the initial portion of the control curve, with small increases in load producing increasing elongation. Rupture occurs suddenly and cleanly. Curves taken from some specimens demonstrate an even greater ability to stretch prior to rupture.

Elongation.—The percentage elongation to the first point of stress was plotted for six bovine carotid artery pairs. Readings were taken from contiguous arterial rings subjected to ficin, papain, and no treatment, respectively, and were plotted for each set of vessels. The results are shown in Figure 6. The great variability among vessels from different donor animals is well illustrated, pointing to the need for comparing the results of treatment on segments taken from the same animal.

Ficin-treated tubes did not elongate to any great extent, for reasons given below. The papain-treated vessels, on the other hand, showed in some vessels a marked ability to stretch compared with controls, while in others this phenomenon was less marked. The averages indicated some increased extensibility. The causes for this variability are being sought in further studies to evaluate the effects of age of the donor animals on elastic behavior of vessels (some of the arteries were from old milk cows brought to slaughter) and to assess further other variables which may be involved in this particular digestion process.

Three factors are probably operative in limiting the extensibility of ficin-treated collagen tubes. The first is formalin treatment, which, while employed to improve the handling qualities of the material for employment as arterial grafts, contributed to its rigidity by cross bonding the collagen fibers to each other, i. e., unformalinized tubes are somewhat more extensible. Secondly, treatment with ficin, by destroying most of the elastica and muscle, permitted

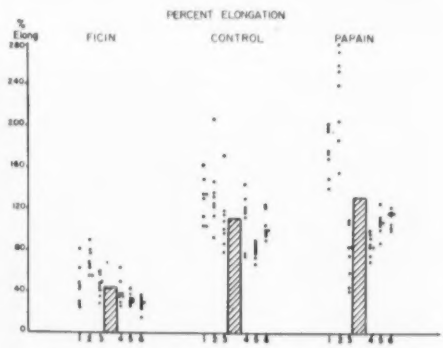


Fig. 6.—Per cent elongation. The scattergrams depict results obtained from six carotid artery pairs, numbered along the abscissa. The shaded bars represent the mean values for each type of enzyme treatment.

considerable spontaneous dilation of the arterial ring even before the application of any stressing force. Finally, collagen itself is a relatively unyielding material when compared with elastica. This is demonstrated by its high Young's modulus.

Breaking Strength and Tensile Strength.—Figures 7 and 8 and the Table provide information on breaking strength and tensile strength of ficin-treated and control preparations. Most observations were made on bovine carotid preparations. A few tests carried out on bovine and human aorta are also included and follow the pattern set by the carotid studies.

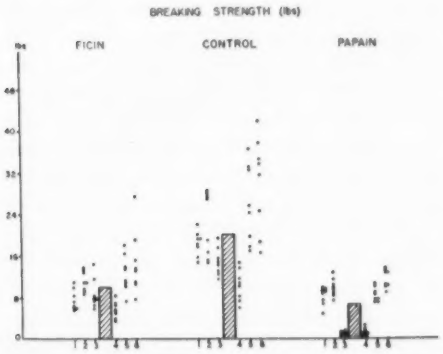


Fig. 7.—Breaking strength. The breaking strength for six carotid artery pairs is shown. The shaded bars represent mean values for each type of enzyme treatment.

It is seen that the breaking strength of the intact artery is greater than that of the collagen tube, but when adjustment is made for difference in wall thickness, as is done in the calculation of tensile strength, the results for each preparation become comparable. Tensile strength could be determined with fair reliability only for collagen and control preparations. Our formic acid preparations of carotid elastica broke under only a few grams of tension (averaging

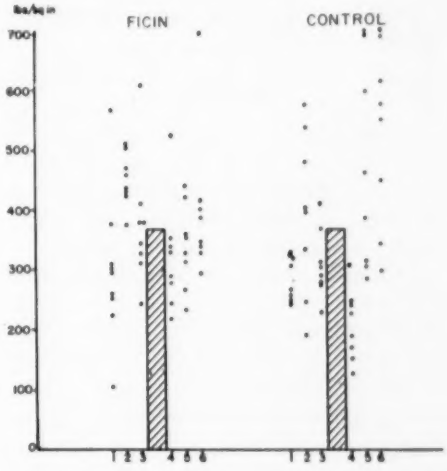


Fig. 8.—The tensile strength in pounds per square inch is shown for six carotid artery pairs. The shaded bars represent mean values. It is seen that figures for ficin-digested arteries and control vessels are comparable.

TABLE 1.—*Stress Studies on Arteries*

Artery	Treatment	Determinations, No.	Av. T.S.*	Av. B.S.†	Elongation, % Av.
Cow carotid	Control (C)	48	369	20.2	111
	Ficin (F)	48	371	10.0	44
Calf carotid	C	2	>400	>18.2	71
	F	2	467	7.3	13
Cow abdominal aorta	C	2	397	21.7	72
	F	2	885	14.7	22
Calf abdominal aorta	C	4	497	21.2	58
	F	4	399	10.3	19
Calf thoracic aorta	C	4	502	31.8	52
	F	4	491	16.6	16
Human thoracic aorta	C	2	268	15.6	45
	F	3	370	11.6	29

* Tensile strength, lb./sq. in.
† Breaking strength, lb.

about 20 gm.), and our observations here were not numerous enough for significant conclusions to be drawn. There is only 5% to 12% elastica in a bovine carotid, as determined by estimation from Verhoeff-stain preparations. Hass's measurements were made on human aorta (35% elastica tissue),[4,5] and we intend to repeat those observations.

Papain preparations could not be used for tensile strength determinations, since the thickness of the elastica layer could not be accurately measured in such incompletely digested material.

Comment

Collagen makes a major contribution to the strength of the arterial wall. The elastica, while playing other important functions in the normal artery, does not seem to have as high a resistance to extensile forces.

In arteries such as the femoral and carotid the elastica constitutes so small a percentage of the thickness of the vessel wall as to further lessen the likelihood of its contributing in major fashion to vessel strength. Again, in these vessels, we find much of the elastica disposed longitudinally in the adventitia in such fashion as to counter elongation forces rather than those of distention.

Our tension curves do not duplicate exactly those illustrated in the literature. However, it does seem as though a vascular implant composed solely of elastica would dilate to several times its resting diameter under increasing stress, with very little effective barrier to dilation and aneurysm formation being provided. Burton[6] has stated that elastic fibers are actually 5 to 10 times more extensible than rubber.

No one can deny the importance of the muscle-elastic apparatus in the normal living artery, where it damps the systolic thrust of the heart and levels off the pressure curve throughout the cardiac cycle. However, in an arterial implant it is not necessarily true that without elastica or elastic behavior the preparation is not a useful one, or that integrity of the elastica is essential to the strength of an arterial graft. It is well known that elastic behavior is soon lost in initially elastic implants either because of the ensheathing of the implant in unyielding host connective tissue or because of later degenerative changes in the elastica—phenomena commonly observed where homografts are employed. Only in an autograft is permanent preservation of arterial elements and behavior possible.

Collagen rings of arterial origin are not very distensible and in this respect bear some analogy to the senile aorta. These rings are about 35% greater in diameter and in length when compared with their pretreatment measurements, indicating that in the intact empty artery the spring-like pull of the elastica keeps the collagen from full extension. The resemblance of the collagen tube to the nonatheromatous senile artery becomes further apparent from the fact that the loss of elastic behavior with age is very similarly associated with dilatation and elongation of the vessel. Hallock and Benson[7] noted a 39% distensibility in a 20-year-old-aorta subjected to 200 mm. Hg intraluminal pressure, while an 80-year-old vessel stretched only 5% under similar stress, partly because it was already stretched or dilated and partly because it was sclerotic or, one might say, "collagenized."

A concept of the behavior of the collagenous and elastica elements of the arterial wall at rest and under stress is illustrated in Figure 9. It summarizes information obtainable from the literature as well as observations we were able to make in its support. In the empty resting state, an artery is contracted by muscle and the spring-like action of the elastica. In diastole, the stress applied to the vessel wall may still not distend the vessel to the point where the collagen is taut. The diastolic pressure load, if low, may, in other words still be born by the muscle-elastica system. When the artery is further distended by increase in the intraluminal pressure, the collagen, stretched and relatively undistensible, offers the main resistance to the force applied.

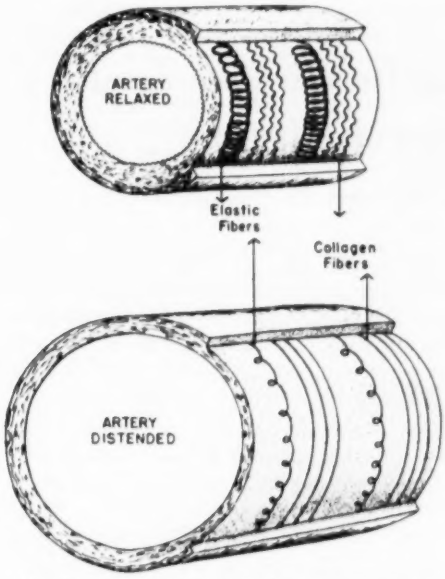


Fig. 9.—Probable behavior of artery components under stress. In the undistended artery, the collagen is relaxed by the spring-like pull of the elastica. In the distended vessel, the collagen is taut, preventing further dilatation. The elastica is still capable of stretch beyond this point, were it not for the resistance offered by the fibrous tissue.

The diagram also suggests that were the collagen weakened or absent the elastica would be capable of being further elongated.

We have prepared collagen tubes of various types by enzymatic digestion of bovine arteries, and have been implanting these into the dog aorta for some time.[1] The removal of the major portion of the muscle from these heterografts has markedly diminished the intensity of the cellular reaction to such implants. Long-term observations are necessary to determine the fate of such implants, and these are being continued.

Summary and Conclusions

The physical characteristics of the elastica and collagen components of the arterial wall have been investigated.

Collagen derived from arteries by enzymatic digestion is highly resistant to mechanical stress. It appears to have the greatest tensile strength of the various tissue substances making up the intact artery.

Purified elastica possesses the properties of extensibility and retractibility but is a relatively weak substance.

The fact that elastica persists in histologically recognizable form in arterial homografts may unduly exaggerate the importance of this layer to the integrity and strength of the graft.

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A Preliminary Investigation of Dermal Heterografts (Leather) as Prostheses for Vascular Defects

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Since the advent of blood-vessel resection in surgical procedures, methods of restoring vascular continuity have become of paramount importance. Such methods have been numerous and varied, and indeed are still the subject of considerable study. That the ideal vascular prosthesis has not yet been realized is suggested by a review of the diverse and sundry substances that have been employed and their various faults. A partial list of nonviable materials that have been utilized as vascular prostheses includes magnesium,[19,26] ivory,[25] aluminum,[3-5] gold-plated metals,[3-5] silver tubes coated with paraffin,[22,34,35] glass,[3-5,24] siliconized rubber,[11] absorbable fibrin,[33] and stainless steel.[1] More recently attention has been directed toward synthetic plastic materials such as Teflon,[7] Saran,[7] Dacron,[7,8] Orlon,[15,21,17,18,7,28,37] Lucite,[9,16] Vinyon,[2,6,21,15,13,7,8,36] nylon,[30,31,10,7,27,29] polyvinyl formalinized sponge (Ivalon),[14,20,32] and polyethylene.[9,12,23] Numerous varieties of fresh, fixed, or frozen vascular auto-, homo-, and heterografts have been used. In the majority of these substitutes criticism has been directed toward one or more of the following: availability, rigidity, thrombosis within the graft, inflammatory response by the host tissues, and the development of calcification. Undoubtedly it will be many years before universal agreement is reached regarding the ideal vascular substitute.

Numerous investigators reporting their experiences with vascular restoration both experimentally and clinically have listed various criteria for successful vascular prostheses. In general these are concerned with availability and ease of fabrication to the particular size needed, the ease of suturing, the tolerance by the host tissues with a minimal inflammatory reaction being most desirable, the lack of systemic toxicity, the lack of calcification in adjacent tissues with ensuing years, their durability, and their pliability.

We have recently become interested in the feasibility of employing some type of leather as a vascular type of prosthesis. The present study is concerned with our initial efforts in this direction. We were attracted to this substance because of its durability, pliability, and availability. Since it is an inert animal tissue it should be well tolerated and have no noxious effects apart from the chemicals used in its preparation. In this discussion we shall present our preliminary observations with chamois, skiver, and lambskin.

Methods

Chamois.—This is defined in a standard text[38] regarding leather manufacture as, "Leather produced from pickled sheepskin fleshers by tanning with cod-liver oil." (A flesher is the sheepskin after removal of the grain layer or skiver or hair follicle layer. By tanners this part is referred to as the thermostat layer of the sheepskin in distinction to the reticular layer or the dermis).

To prepare chamois the main steps are as follows: pickled sheepskins (sheepskins mixed chiefly with brine) are washed in running water to remove the salt. Subsequently they are pressed hydraulically to express the water and grease. After drying they are again mixed with water in a drum and then individually passed through a splitting machine which removes the grain or hair follicle layer from the flesh layer. The grain layers are called sheep skivers while the flesh layers are used to make chamois.

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The flesh layers are then mixed in a drum with cod liver oil for several hours during which time the oil distributes itself through the layers of sheepskin and penetrates them to some extent. The skins are hung in a damp humid room for two or three days. During this time some chemical reactions, and these are not known exactly, take place between the oil and the hide proteins. A second drum mixing with cod liver oil and another hanging in a humid room complete the process of chamoising. Modifications of chamoising are produced by using other oils such as seal, whale, shark, etc., and other types of mixing machines. Thus the main chemical employed in the treatment of sheepskin for the manufacture of chamois is cod liver oil.

Skiver.—The grain split of a sheepskin or that layer of the hide that includes the hair follicles is termed sheep skiver. After this layer has been split from the sheepskin it is treated by synthetic tannins composed chiefly of a mixture of phenolsulfonic acids and formaldehyde. This results in a thin, durable, pliable leather frequently used for hatbands, book bindings, purse linings, etc.

Lambskin.—The pickled skins are first washed with water, kerosene, and sulfonated cod liver oil. This mixture is pressed out and the skin is then mixed with one of the synthetic tannins for its final preparation. It should be noted that the lambskin is treated with a tannin in contrast to the cod liver used for chamois.

The leathers used in our experiment were obtained from a commercial shop selling various leather products. The chamois was of the highest grade and consisted of a hide approximately 2×3 ft. The skiver and the lambskin were casual samples selected because of their pliability and thinness from the stock. It was not possible to trace back the exact steps in the preparation of our particular samples, this study being of a preliminary nature only.

Preparatory to use in the experimental animals the chamois and other leathers were first washed thoroughly with soap and water and then sterilized by immersion for 24 hours in a 1:1000 solution of benzalkonium (Zephiran) chloride.

Leather grafts or patches were placed in 36 mongrel dogs, utilizing chamois in 25 animals, skiver (2 varieties) in 7, and lambskin in 4. These preparations and the results are summarized in tables 1-4. All animals received penicillin and streptomycin daily for one week postoperatively.

Right Ventricular Patches.—Endotracheal oxygen was administered utilizing an automatic ventilator after intravenous anesthesia with pentobarbital (Nembutal). Right thoracotomy was done in six dogs through the fourth interspace and the pericardium opened anterior and parallel to the phrenic nerve. An umbilical tape was placed around the superior vena cava proximal to entrance of the azygos vein. A second tape was placed around the inferior vena cava. Inflow occlusion was then established by traction on these umbilical tapes. The heart was allowed to beat for several seconds and subsequently a 2.0 to 2.5 cm. full-thickness portion of the right ventricular wall was excised. A previously cut circular piece of chamois was sutured to the edge of this defect with a continuous 0000 nonabsorbable surgical (silk) suture. As soon as the suturing had been completed the vena caval tapes were released. In a few instances additional sutures were needed to control bleeding along the circumferential suture. The pericardium was loosely approximated with interrupted sutures of 000 nonabsorbable surgical silk, the lung reexpanded, and the chest wall closed in anatomical layers with continuous 00 chromic absorbable surgical (gut) sutures. Of six dogs none showed any morbidity or appreciable disturbances postoperatively. Five dogs have been killed from intervals varying from 62 to 93 days. One animal is still living and well, 161 days after operation.

Thoracic Aortic Patches.—Six dogs were anesthetized with intravenous pentobarbital and maintained during operation with oxygen through an endotracheal tube connected to an automatic ventilator. Left thoracotomy was done through the fourth interspace. A segment of the descending thoracic aorta was isolated by bilateral ligation of two or three pairs of intercostal arteries. A Potts-Smith clamp was placed about the mid-portion of the descending thoracic aorta and gradually closed. An ovoid portion of the aorta approximately 1×2 cm. was excised and replaced by a patch of chamois. The chamois was sutured with a continuous 00000 nonabsorbable surgical (silk) suture. The Potts-Smith clamp was gradually released. Hemostasis was generally secured with a moderate amount of pressure for a few minutes at the site of any leaking points in the suture line. The lung was reexpanded and the chest wall closed in anatomical layers with continuous 00 chromic absorbable surgical (catgut) sutures.

One animal died one month postoperatively with distemper. None showed any immediate morbidity and none of the remaining five manifested any late difficulties. Four have been killed at intervals from 40 days to 157 days postoperatively; one is still living and well, 152 days postoperatively.

Thoracic Aortic Grafts.—Twenty-three animals were anesthetized and thoracotomy done through the left fourth interspace. After the chest was opened the aorta was mobilized for a greater distance than in the above procedure depending upon the size of the graft to be inserted. The graft had previously been constructed by forming a tube

TABLE 1.—*Right Ventricular Patches—Chamois*

Dog No.	Size of Ventricular Defect Diameter, Cm.	Duration, Days	Results
116	2.0	161	Living and well (June 9, 1956)
101	2.5	93	Killed
139	2.5	84	Killed
141	2.0	67	Killed
23	2.5	62	Killed
142	2.5	62	Killed

of appropriate diameter (0.5 or 1.0 cm.) and length (2.0 to 10.0 cm.), and suturing the everted edges together with continuous 0000 nonabsorbable surgical (silk) sutures. After mobilization of the aorta, it was clamped proximally and distally with either a Potts or a DeBakey clamp and a segment was excised. The chamois or other type leather tube was sutured to the open ends of the aorta by a continuous 00000 nonabsorbable surgical (silk) suture, generally using one suture anteriorly and one posteriorly. Occasionally the entire anastomosis was accomplished with one suture.

The distal clamp was released and after the graft had filled with blood, the proximal clamp was removed. When chamois was used as a graft only a minimal amount of bleeding occurred, this usually being at the suture line. One could see the blood passing through the interstices of the chamois, but no appreciable amount of blood was lost in this fashion. Additional hemostatic sutures at the anastomotic sites were inserted as needed.

Of 12 animals in which chamois was used, 5 are living and well 68 to 151 days postoperatively. Two died in the immediate postoperative period, eight days postoperatively, from hemorrhage at the site of leaking anastomosis. Both of these were rather long grafts being 1×10 cm. and 1×5 cm. Two animals died after aortograms with injection of radiopaque medium into the left ventricle at 30 to 117 days postoperatively. Four animals were killed between 83 and 118 days postoperatively.

In 11 animals the aortic graft was constructed of skiver (7 dogs) and lambskin (4 dogs). These proved technically to be difficult materials to handle, tearing with placement of the suture being a frequent occurrence. It was also noted that these materials were quite stiff, and consequently it was impossible to secure adequate hemostasis with usual suturing techniques. The difficulty of utilizing this material is reflected in the high incidence of postoperative complications and generally poor results.

Of the seven animals in which skiver was used, only one survived for any appreciable length. This animal (No. 45) died 35 days postoperatively after direct puncture of the left ventricle for an aortogram. The remaining animals died within 1 to 26 days from either hemorrhage or an empyema superimposed on hemothorax.

Of the four animals in which lambskin was utilized, all died between one and nine days postoperatively either from hemorrhage or empyema.

The length of aortic occlusion in all of the aortic grafts varied from 13 to 19 minutes. No evidence of any paralysis was noted postoperatively.

One abdominal aortic graft has been constructed of chamois, this graft being 0.5×3 cm. in size with occlusion of the abdominal aorta for 18 minutes. The animal is living and well at the present time, 151 days postoperatively. An aortogram shows good visualization without luminal constriction of the abdominal aorta.

TABLE 2.—*Thoracic Aortic Patches—Chamois* (Each Ovoid, About One by Two Centimeters)

Dog No.	Duration, Days	Results
19	157	Killed
68	154	Killed
25	152	Living and well (June 9, 1956)
5	43	Killed
18	40	Killed
71	27	Died, pneumonia; graft intact no thrombosis

Results

Right Ventricular Patches.—None of these animals evidenced any postoperative morbidity or mortality. At the time of killing of five of these six dogs 62 to 93 days following insertion of the chamois patch, a moderate degree of adhesive pericarditis was noted in the area of the right ventricle that had been grafted. The interior of the right ventricle revealed a layer of fibrous tissue immediately adjacent to the chamois graft with an inner layer of glistening white endocardium. Although the defect had been created by a discrete through-and-through incision, the healed residual was saucer-like and showed a gradual change from the

TABLE 3.—*Aortic Grafts—Chamois*

Dog No.	Location of Graft	Size of Graft, Cm.	Time of Occlusion, Min.	Duration of Graft, Days	Results
28	Abdomen	0.5×3.0	18	151	Living and well (June 9, 1956)
7	Thorax	1.0×2.0	16	141	Living and well (June 9, 1956)
50	Thorax	1.0×2.0	15	131	Living and well (June 9, 1956)
106	Thorax	1.0×3.0	15	82	Living and well (June 9, 1956
118	Thorax	1.0×10.0	15	68	Living and well (June 9, 1956)
46	Thorax	1.0×3.0	13	118	Killed
9	Thorax	0.5×2.0	19	117	Died during direct aortography
35	Thorax	1.0×2.0	16	115	Killed
49	Thorax	1.0×2.0	19	110	Killed
81	Thorax	1.0×2.0	15	83	Killed
39	Thorax	1.0×3.0	18	30	Died after aortogram
120	Thorax	1.0×10.0	16	8	Died from hemorrhage at leaking anastomosis
64	Thorax	1.0×5.0	--	8	Died from hemorrhage at leaking anastomosis

TABLE 4.—*Aortic Grafts—Skiver and Lambskin*

Dog No.	Location of Graft	Material	Size of Graft, Cm.	Time of Occlusion, Min.	Results
56	Thorax	No. 1	1.0×2.0	16	Found dead in cage next morning, hemorrhage at anastomosis
58	Thorax	No. 1	1.0×2.0	16	Died overnight, hemorrhage
55	Thorax	No. 1	1.0×2.0	15	Died 26 days postoperatively, hemorrhage at suture line and empyema
45	Thorax	No. 1	1.0×2.0	19	Died 35 days postoperatively, following left ventricular aortography
98	Thorax	No. 2	1.0×2.0	16	Died 3 days postoperatively, hemorrhage at anastomosis
11	Thorax	No. 2	1.0×2.0	16	Died 6 days postoperatively, chest filled with infected hematoma
84	Thorax	No. 2	1.0×3.0	15	Died 23 days postoperatively, empyema
59	Thorax	Lambskin	1.0×2.5	--	Died overnight, hemorrhage
96	Thorax	Lambskin	1.0×2.0	14	Died 6 days postoperatively, empyema
60	Thorax	Lambskin	1.0×3.0	15	Died 8 days postoperatively, hemorrhage from leaking anastomosis
54	Thorax	Lambskin	1.0×3.0	15	Died 9 days postoperatively, hemorrhage from leaking anastomosis

thickness of the covered patch to the full-thickness of the ventricular wall.

Thoracic Aortic Patches.—One of these six dogs died 27 days postoperatively from distemper. Gross examination of the aorta and the graft showed the latter to be intact and already partially covered with a thin layer of endothelium except for its most central area. Here a layer of fibrous tissue covered the chamois.

Four dogs were killed from 40 to 157 days postoperatively. In these specimens the patch was completely or partially covered by endothelium on its luminal side. Externally a rather thick layer of fibrous tissue had formed adjacent to the chamois. Although that portion of the aorta containing the patch was quite pliable, it was not as supple as normal aortic tissue (Fig. 1*a* and *b*.).

Aortic Grafts.—Chamois: Of these 12 dogs 2 died from the technical error of a leaking anastomosis eight days postoperatively. Two animals died as a result of left ventricular aortography, 30 and 117 days after operation. Five are living and well 68 to 151 days postoperatively. Four dogs were killed for examination 83 to 118 days after insertion of the aortic graft.

Examination of the chamois at various stages after its insertion revealed that initially (about one week) a thin fibrin layer accumulated on the inner aspect. Subsequently this layer became invaded by fibrous tissue with endothelialization from

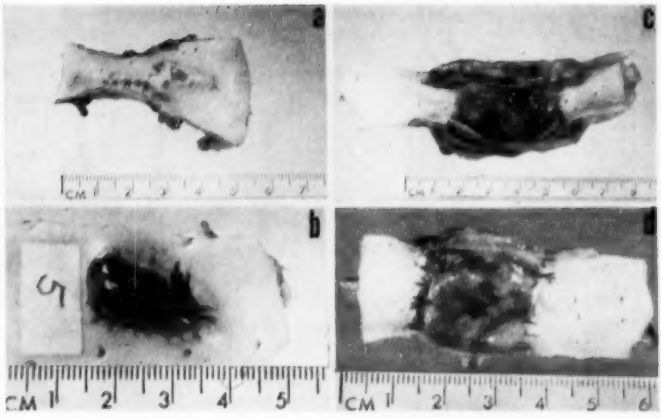

Fig. 1.—*a*, Dog 19, thoracic aortic chamois patch, killed after 157 days. Note the faint depression of the wall in the area of the defect, covering of the patch by white glistening endocardium, and partial obliteration of the nonabsorbable surgical (silk) sutures. *b*, Dog 5, thoracic aortic chamois patch, 43 days. A thin layer of endocardium has partially covered the patch and to some extent the silk sutures are obliterated. *c*, Dog 81, thoracic aortic chamois graft after 83 days. Coverage of the graft by endothelium is seen and slight wrinkling of the graft is noted. Observe the fibrous layer external to the graft corresponding to the adventitia. *d*, Dog 35, thoracic aortic chamois graft 115 days postoperatively. The chamois had been covered by endothelium; a moderate amount of wrinkling is noted.

adjacent normal tissue. The thickness of the fibrin layer varied as the degree of wrinkling, the fibrin being thicker in a deep wrinkle than elsewhere. These gross observations were supported by subsequent microscopic examinations. In the grafts that were oldest the luminal side of the chamois was completely covered with glistening endothelium. External to the graft there was a moderately thick (2 to 4 mm.) layer of fibrous tissue corresponding to the adventitia (Fig. 1, *c* and *d*).

Fifteen aortograms were done in nine of these animals at intervals varying from 14 to 129 days postoperatively. These were done either by direct left ventricular puncture or by cannulation of a femoral artery and retrograde passage of a polyethylene (Polythene) catheter into the ascending aorta. Approximately 20 ml. of radiopaque medium (90% diatrizoate [Hypaque] sodium or 76% of a mixture of sodium and methylglucamine salts of diatrizoate [Renografin]) were then injected.

In no instance was any gross constriction or narrowing of the lumen suggesting thrombosis seen. Some narrowing at the anastomoses was noted, but this was believed to be due to the method of suturing. Variable amounts of kinking and dilatation were demonstrated, slight in degree and attributed to a minor discrepancy between vessel and graft sizes (Fig. 2).

In one animal (No. 28) a 3.0 cm. long graft was inserted into the abdominal aorta. Aortograms were made 24 and 136 days postoperatively. These revealed a barely perceptible narrowing of the lumen at the graft site (Fig. 2).

Skiver and Lambskin: Technically both these types of leather were so difficult to suture that hemorrhage and empyema were the usual result. In those animals that did survive (No. 45 and 55) the gross appearance was similar to that described for chamois. Since the skiver was thinner than the lambskin it was slightly less rigid and somewhat easier to suture.

Microscopic Changes

The histologic preparations (Figs. 3 and 4) showed several rather distinct changes occurring in those animals where chamois was implanted, either as a patch or a graft.

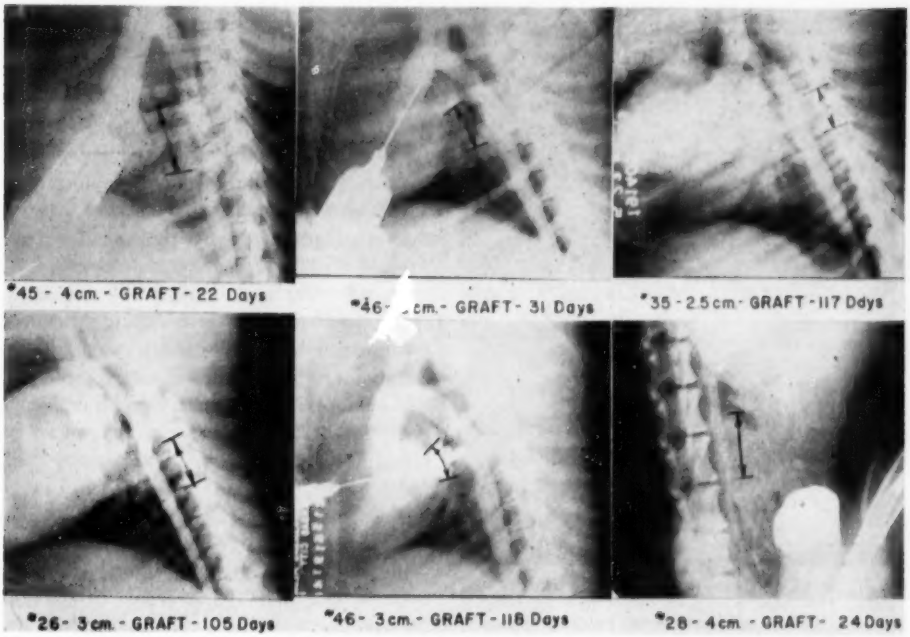

Fig. 2.—Aortograms following suture of chamois grafts to aortic defects. In all instances there is a good aortic stream without appreciable narrowing of the graft lumen.

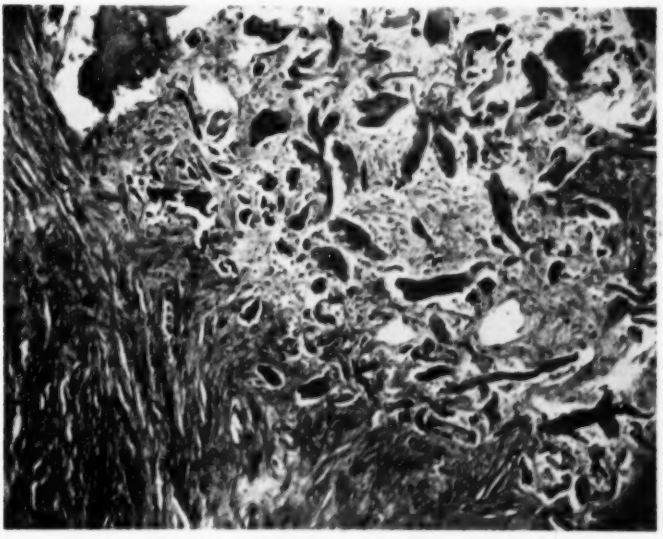

Fig. 3 (Dog 71).—Aortic chamois patch. The dog died 27 days postoperatively from distemper. Permeation of the shreds of chamois by proliferating fibroblasts and new capillaries may be seen. Note the absence of any appreciable cellular reaction in tissue adjacent to the patch. (Magnification × 100.)

Within several days there began the growth of fibrous tissue, chiefly fibroblasts and capillaries, from adjacent tissue permeating and invading the fragments of chamois. By four weeks after insertion of the chamois this fibrous tissue had become well-organized with collagen formation and subsidence of edema among the fibroblasts. After four weeks the fibrous tissue became more dense, better organized, and strand-like. Con-

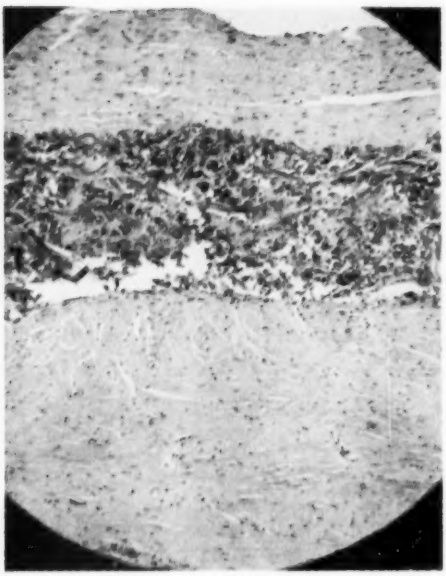

Fig. 4 (Dog 35).—Aortic chamois graft. Dog killed 115 days postoperatively. The chamois is seen in the middle of the field, its fragments surrounded by strands and sheets of mature collagenous tissue. Toward the lumen is a layer of adult fibrous tissues covered by endothelium. Toward the bottom of the field is a thicker layer of collagen containing an occasional new blood vessel and corresponding to the adventitial layer. Note the lack of any inflammatory cellular reaction near the chamois. (Magnification ×33.)

comitantly with invasion of the chamois by fibroblasts there was the development of a fibrous layer on each side of the chamois. On the intimal side this varied in thickness according to the wrinkling of the graft. Later it became covered by endothelium growing from the adjacent normal aortic intima.

On the opposite side of the graft corresponding to the adventitial layer a covering of loose fibrous tissue first developed. By the fourth week this was well-organized into strand-like areas of rather dense collagen tissue.

A distinct feature was the lack of appreciable inflammatory response in adjacent tissues. The area of the graft appeared quite distinct from the inner and outer layers of fibrous tissue as far as any inflammatory reaction was apparent. Of interest was the appearance of nonabsorbable surgical (silk) suture material near the chamois which exhibited much more round-cell infiltrate and giant-cell formation about it than did the chamois.

In those grafts placed in the right ventricle there was more of a cellular reaction in adjacent myocardial tissues than in the aorta, although again the reaction was less than that provoked by the nonabsorbable surgical (silk) sutures.

In the older grafts (118 and 157 days) there was a change toward basophilism, as demonstrated in the fibrous tissue suggesting a transformation toward cartilage. In one of the sections isolated cells were found composed of basophilic material and nuclei resembling cartilage cells although these could not be definitely identified as such.

The graft composed of skiver was easily recognized by the dead "ghost-like" hair follicles and its compactness as compared with the fragmented appearance of chamois. In addition, more of a cellular reaction was noted in this section than in those of the chamois.

Comment

Several considerations have impressed us in our observations during the use of chamois, skiver, and lambskin. Chamois is technically a most satisfactory substance with which to work; it is easy to suture and it approximates well with adjacent tissue so that leakage at a suture line does not become a problem. Although porous, only a minimal amount of blood oozes through its wall and bleeding is not encountered such as it is in some of the porous plastic cloths. Its pliability similarly contributes to its ease in handling. The lack of tissue reaction is similar to that found for polyvinyl formalinized sponge and indicates a high degree of tissue tolerance. When studied microscopically to periods up to 118 days the amount of fibroplasia is not excessive and only slightly more than the thickness of adjacent normal tissue. These observations are further confirmed by the clinical behavior of the dogs, none of our 25 animals evidencing any appreciable thrombosis or dis-

tortion due to scar formation in the periods studied. The lack of cellular reaction and penetration of the graft by fibrous tissue suggests that it acts as a scaffolding until the vascular defect is reconstructed by host tissues. It is suggested that these qualities offer promise to chamois as a vascular prosthesis and that its use deserves further investigation.

Skiver and lambskin present the technical problems of tearing with passage of a needle through their substance and of being slightly rigid, both of these contributing to a difficult vascular anastomosis generally resulting in early or delayed hemorrhage. It seems likely that these qualities are imparted to these leathers by their tanning processes.

Summary

Chamois has been investigated as a vascular prosthesis in 25 dogs, utilizing it as a right ventricular patch in 6, as a thoracic aortic patch in 6, as a thoracic aortic graft in 12, and as an abdominal aortic graft in 1.

Examination of the gross specimen and of the living animals by aortography failed to reveal any appreciable thrombosis. Chamois is well tolerated by host tissue and acts as a support through which fibrous tissue permeates.

Skiver (two varieties) was used in seven dogs and lambskin in four dogs as grafts for the thoracic aorta. These materials proved technically unsatisfactory for suturing in our hands.

From these preliminary results further observation in the feasibility of chamois as a vascular substitute appears warranted.

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Popliteal Vein Ligation in the Treatment of the Lower Limb Stasis Syndrome

A Three- to Six-Year Evaluation

THOMAS O. MURPHY, M.D.; JOHN J. HAGLIN, M.D.; EDWARD C. EMERSON, M.D., and DAVITT A. FELDER, M.D., Minneapolis

The reports of Buxton[1] and his colleagues on the interruption of the superficial femoral vein for long-standing deep phlebitis of the lower extremity, and the earlier phlebographic studies of Luke[2] and Bauer,[3] preceded an era of interest in interruption of the popliteal vein as a method of treatment for the lower limb stasis syndrome. In 1948, Bauer[4] presented a technique of popliteal vein ligation which became popular.

Between the years of 1949 and 1953, inclusively, 72 popliteal vein ligations were performed in 63 patients at the University of Minnesota Hospitals. Nine patients had bilateral popliteal vein ligations. This report is a three- to six-year follow-up of these patients.

Twenty-one patients were males, and forty-two were females. These patients had severe and chronic disease, with symptoms from 3 to 36 years prior to this operative intervention. The mean duration of symptoms prior to surgery was 10 years. Forty-eight patients were markedly overweight, while fifteen had a near-normal weight. The majority of the patients had undergone multiple previous operations, with the average patient having three previous operations for relief of symptoms.

The physical examination of the extremity, concerned (Tables 1 and 2) showed the greater saphenous vein to be incompetent in 33 of the 72 extremities, and it was either concurrently ligated and stripped at the time of the popliteal vein ligation or within the following year. The remaining 39 extremities had undergone previous greater saphenous vein removal, or it was described as normal.

The short saphenous system had undergone previous surgical resection in 9 instances, was diagnosed as incompetent in 45 instances, and was diagnosed as normal in 18 instances. If it was incompetent it was stripped at the time of the popliteal vein ligation. Although its importance was not emphasized, the presence of incompetent

TABLE 1.—*Characteristic Features in Seventy-Two Extremities Subjected to Popliteal Vein Ligation*

	No.	Per Cent
Pitting edema	72	100
Induration	72	100
Ulceration	63	87
"Bursting" pain	27	38
Mean duration of symptoms	10 years	

TABLE 2.—*Status of the Superficial Veins at the Time of Popliteal Vein Ligation in Seventy-Two Extremities*

Status	No.	Per Cent
Greater saphenous incompetency	33	46
Greater saphenous previously resected	39	54
Lesser saphenous incompetency	45	63
Lesser saphenous previously resected	9	12
Lesser saphenous normal	18	25
Communicating vein incompetency	72	100

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communicating veins was noted in every instance in the physical examination prior to the popliteal vein ligation.

A stasis ulceration was present in 63 of these extremities and absent in 9. The ulcerations were all healed prior to popliteal vein ligation. Severe ankle edema was a universal complaint.

The "bursting" type of pain was not as common in this series as in the series described by Bauer.[5] It was noted in 27 instances and absent in 45. A history of thrombophlebitis was obtained in only 45 of the 72 extremities under consideration.

The following were the indications for popliteal vein ligation:

1. The presence of lower limb stasis syndrome, not kept under adequate control with conservative management.

2. Evidence of popliteal vein incompetency demonstrated by retrograde phlebographic study.

In conservative management the following details were observed: (1) good foot hygiene; (2) adequate external support to the leg; (3) elevation of the foot of the bed and even bed rest in severe cases; (4) skin grafting to ulcer sites. Only when the above measures failed was a popliteal vein ligation done.

The technique of the surgical procedure was as that described by Bauer [4,5,6] and does not need further description here, except to say that the ligation and division of the vein was well above the joint space.

Results

The 63 patients of this series were recalled to the vascular clinics for evaluation and were seen by one of us within the year previous to this report, while this evaluation was in mind. We were fortunate that only a very few patients operated upon were lost from the series, and these instances are not reported on.

The results of the operative procedure were evaluated from the standpoint of the effect upon skin ulceration, peripheral edema, and pain.

The instances graded as "failures" were those in which there was a recurrence of the ulceration within one year which needed further surgical therapy to keep it healed.

The "equivocal" result describes those instances in which there was no objective change from the preoperative status. Early recurrence of skin ulceration which could be rehealed and maintained by conservative means was also graded as equivocal.

The "fair" result describes an extremity in which the ulcer remained healed but in which there was pain and/or severe edema that necessitated further care.

The "good" result describes an extremity in which the ulcer, if present, remained healed, with relief of edema and pain, with or without the use of good elastic support to the legs.

Table 3 lists the late results of the operative procedures. Thirty extremities, or 42% of the series, were aided by the operation, while 42 extremities (58%) were without relief. In 36 instances (50%) there was recurrence of the ulceration within one year; however, 9 of these were healed and maintained with conservative management.

TABLE 3.—*The Results from Three to Six Years After Popliteal Vein Ligation in Seventy-Two Extremities*

Result	No.	Per Cent	
Good	24	33	42
Fair	6	9	
Equivocal	15	21	58
Failure	27	37	

Comment

It is our opinion that the evaluation of the results of this type of surgery depends upon two factors: the accuracy of the postoperative evaluation and the critique used in choosing the patient for the operative procedure.

In this series, patients have been continuously followed by the same group of surgeons that originally so enthusiastically performed the operation. All patients have

been reevaluated within the past year, and thus the final evaluations are felt to be as accurate as possible.

The selection of patients depended upon the presence of uncontrolled stasis changes in the lower extremity, with evidence of "popliteal incompetency" as demonstrated by retrograde phlebography. The latter may have been our greatest source of error.

It has been shown [2,7] that the injection of a hyperbaric solution of radiopaque substance into the popliteal vein may flow retrograde past normal values if the patient is in an upright position. Further, the popliteal vein was found to be incompetent in only 8% of a large group of limbs with the stasis syndrome studied by isoflow [8] phlebography and reported by two of us. The popliteal vein was visualized as a bifid structure across the popliteal space in 52% of this latter series. This figure is close to that from anatomical studies of William,[9] who reported a 66% incidence of bifid popliteal vein. In only three instances was bifid popliteal vein noted in the operative reports of this series, and in such instances both veins were ligated.

Postoperative isoflow phlebograms have been compared with similar preoperative studies in eight patients (Fig. 1). It may be noted that the postoperative study shows a large venous channel in the popliteal space. This may be a dilated collateral or a bifid popliteal vein not visualized in the preoperative phlebogram and overlooked at surgery.

The report of Bauer,[6,10] that over 74% of his series have been free from recurrence of symptoms, is not borne out in this study,

Fig. 1.—*A*, preoperative isoflow phlebogram. *B*, phlebogram taken eight months after popliteal vein ligation, *X* indicates point of popliteal vein ligation and division.

as here only 42% were free from recurrence. The fact that Bauer's series was much larger than ours should be examined. In order to approximate the results of Bauer statistically we would need 100 more cases with only good results. This, of course, is extremely improbable. It is difficult to know if Bauer's indications for surgery are comparable with ours. It is possible that we might have preferred, and succeeded in, conservative management of the lower limb stasis syndrome in some of the patients operated upon successfully in Bauer's series.

In spite of the high incidence of failure found in this study, it appears that popliteal vein interruption may be of some value in some instances. It is our contention that the choice of patient for popliteal vein ligation must depend upon a more accurate evaluation of popliteal vein incompetency than has heretofore been presented. Long-term follow-up of patients chosen on the basis of isoflow phlebographic methods (Fig. 2) may yield a more rewarding result.

Summary

A three- to six-year evaluation of the results of popliteal vein ligation is presented. Forty-two per cent of the patients showed improvement, and fifty-eight per cent were without relief of their symptoms. A more accurate method of evaluation of popliteal vein incompetency may be needed for the choice of patients with the lower limb stasis syndrome that are submitted to this procedure.

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DISCUSSION

ON PAPERS BY DRS. PRATT AND LEVINE AND MURPHY, HAGLIN, EMERSON, AND FELDER.

DR. THOMAS C. MOORE, Muncie, Ind.: I have been interested in studying the problem of lower extremity edema by means of functional venographic techniques. A portion of this study was presented before this Society last year. Those investigations have been continued and expanded in certain areas. We have not, as yet, encountered a single instance of true functional regurgitant flow in the deep venous system when muscle exercise of the dependent extremity is employed. Some regurgitant flow in the deep venous system is found in the normal lower extremity in quiet dependency. This regurgitant flow in quiet dependency is less, rather than greater, in the postphlebitic limb with a recanalized popliteal-femoral venous trunk. These observations have led us to regard operative interruption of venous channels in the post-thrombotic as functionally unsound. We have employed good compressive support in all cases and have found this method of treatment to be quite satisfactory.

DR. JOSEPHUS C. LUKE, Montreal, Canada: Some time ago, in discussing this problem, I had gone through the literature and had come across 25 different operations performed on the postphlebitic leg. They have come and they have gone, and it is certainly my belief that you cannot correct the underlying pathology in this disease; you cannot repair it with new veins. It may be that this Society will be able to find a way to put in venous grafts as we are putting in the arterial grafts, but until that time comes we cannot correct the underlying pathology. Therefore, these operations, at best, are a very temporary, and at the worst a very expensive, proposition, with long layoff of the patient and hospitalization, and the results, in the main, have been indifferent. I have completely given up all surgery, with the exception of stripping incompetent varicose veins and the occasional skin grafting of the large ulcer.

We have followed a conservative program for nearly eight years, and the more I see of it the happier I am that we are doing so, and I expect to continue.

DR. ROBERT R. LINTON, Brookline, Mass.: I have been interested in the post-thrombotic syndrome for many years, perhaps longer than most members of this Society. I have come to the conclusion after these many years that there is a place for the surgical treatment of this condition, providing that one carries out the correct procedure. It is important that it be performed in the complete radical method I have previously described.

[Slide] I think there is a great deal of misunderstanding in regard to the terminology of this condition. In my opinion, the treatment of the post-thrombotic syndrome without ulceration is entirely different from that with ulceration. I would agree with the essayists that the post-thrombotic syndrome without ulceration is best treated in the majority of cases by an adequate elastic support, but the most satisfactory method of rehabilitating a patient with the post-thrombotic type of ulceration is the utilization of surgical measures.

The surgical treatment of the ulcerated extremity should only be performed after complete healing of the ulceration, either by skin grafting the ulcer or, as is done in the majority of my patients, by the ambulatory means, using compression bandages.

After the ulceration and the dermatitis has been healed, the five following steps in the surgical treatment—and they are almost all of equal importance—should be carried out to get the best results.

First, it is important that the superficial veins, including the long and short saphenous trunks and many of their tributaries, should be removed.

Second, the deep venous systems should be interrupted, either at the superficial femoral vein level just distal to the profunda femoris in the groin or the popliteal vein at the knee. I personally prefer the former, since it is an easier vein to expose and interrupt.

Third, it is of utmost importance—and perhaps this is the most important step—to interrupt the communicating veins between the deep and superficial systems of veins in the lower leg below

the knee. This can be done through a vertical incision on the inner side of the lower leg.

Fourth, through this same incision, the deep fascia is excised in an attempt to improve the lymphatic drainage of the skin and subcutaneous tissues, and at the same time many of the superficial veins, which otherwise would not be exposed, can be removed. It also permits an easier and more satisfactory closure of the skin incision without tension.

Fifth, it is of extreme importance that the patients be instructed to wear an adequate elastic support for an indeterminate period of time, from the toes to just below the knee.

One of the great difficulties in assessing the value of the various procedures which have been recommended for the post-thrombotic state has been the lack of good follow-up statistics on the late results by the various procedures that have been utilized. I wish to report here the follow-up studies on a group of 41 post-thrombotic ulcers that were followed for from four to nine years after the procedure, as I have described it above, was carried out. At the time these patients were examined, it was found that 38, or 93%, of the ulcers were healed and only 3, or 7%, were unhealed. A further period of observation is necessary, and the results will be reported on these patients at a later date, but I can assure you that many of them are my most grateful patients.

DR. RIVLIN, London, England: We, in England, were most enthusiastic about Dr. Bauer's procedure. In fact, after he spoke at the Royal College of Surgeons, all the candidates for the Fellowship had to be able to explain exactly how this was done for the next four years.

It has been tried in England, mainly at St. Bartholomew's Hospital—I don't work there—but it has been found to be a failure, an absolute failure. Now, there is one point I should like to discuss. There was a speaker who said that no one had seen what happened to the deep venous pressures after ligation. As a matter of fact, at St. Bartholomew's Hospital they measured the deep venous pressures and found that immediately after operation they went down. Months later, after other deep veins opened up, the pressures returned to preoperative levels.

I was most interested in Dr. Linton's discussion. His follow-up of from four to nine years, with all due respect, I should say was of little significance. I say this, because the place I work in in London is very specialized. I discovered to my horror that it is more specialized than anything you have in America. I thought America was the home of specialties, but our place in London does nothing except deal with varicose veins. However, at least some good is going to come out of it, I think, because we spend an hour and a half just examining a patient and taking his history the first time he comes in. It is all down on paper; everything is there. We have observed from these very accurate histories of each patient that in some cases, given no treatment at all, these patients with deep venous thrombosis, and with a post-thrombotic syndrome, may have intervals of anything up to nine years with no ulceration.

DR. CRANLEY, Cincinnati: I am sure that there is one thing that we can count on, and that is that every time the subject is mentioned there will be a great deal of discussion. In fact, there was so much discussion last year that all of it was deleted for the printed text. I should like to congratulate Dr. Felder, and I am sure he will point out that he was referring to ligation of the popliteal vein alone and not considering the entire surgical treatment.

In regards to the work of my good friends Dr. Moore and Dr. Shumacker, I think it should be pointed out that we would expect the veins to empty under any condition. If the total outflow of blood from the leg were decreased by only 1% there would be enormous swelling, such as shown in the pictures of Dr. Pratt. In other words, regardless of the amount of disease present we expect that 90%, 95%, or even 99% of the blood passes out of the limb. And the small amount of blood that may be retained in the limb could not be detected by an arteriogram. As I mentioned before this group last year, I believe that the essential pathologic defect is more closely involved with pressure relationships than with volumetric changes.

In regard to Dr. Linton's method of treating these patients, I have used it exactly as he has described it. In the patients who have not been subjected to surgery the recurrence rate is approximately 30%. Of the patients who had surgical treatment there has been only 1 recurrent ulceration in approximately 100 extremities over a four-year period of time.

In this disease, more than most others we treat, therapeutic results are closely related to the degree of treatment. The basic pathologic concepts are known by all. Everybody knows that most of these legs will heal if the patient goes to bed, but frequently we don't elevate the leg high enough for a long enough period of time. Everybody knows an elastic support is good, but most of the elastic stockings simply are not heavy enough to control hydrostatic pressure. Everybody knows that these ulcers of the leg can be healed by a pressure bandage, but few apply a tight enough bandage for a long enough period of time. Finally, everybody knows that removing the diseased veins is helpful, but the point is to remove enough of the diseased veins to get the good results as described by Dr. Linton.

DR. G. DE TAKATS, Chicago: We have struggled with this problem for about 30 years ourselves, and have done everything that has ever been proposed, including femoral ligations, popliteal vein ligations, and sympathectomies.

We have reported on popliteal vein ligations for what we thought were well-selected cases, and I should like to state that we have given them up. In fact, I believe that everybody who has advocated some type of surgery and later on stopped doing it should come out with a retraction.

We found in the follow-up of popliteal vein ligations that they had not done any better than the ones wherein we had ligated perforators and excised indurated areas.

I would hate to see the opinion prevail—I note there is another paper to be given tomorrow before the Vascular Surgery Society—that the best treatment is conservative management with elastic compression, because we have considerable material, as many as 500 patients whom we have followed anywhere from 30 to 20 years and in whom there has been extensive stripping, together with a very careful ligation with perforators, and this has permitted them to go about their daily work without any elastic compression. After the tendency toward ligating deep circulation and a second era, which consisted of stripping, I think we have got to find adequate, simple clinical methods to avoid missing perforators, and when we have that we will have a fairly practical method for dealing with this situation.

DR. DAVITT A. FELDER, St. Paul: Would anyone like to sum up all of the discussion that has gone on here and still walk out of here everyone's friend? It is a bit difficult to do, I think. But it must be mentioned that we do not have a good rationale for ligating any deep veins. I do not think that it is physiological. From what we know of the physics of the thing, it is not logical. I do not want to walk out of here with everyone thinking I am an enthusiast for ligating deep veins. I do not think that most thoughtful surgeons are enthusiastic about such procedures. However, we have presented the fact that there has been some benefit from such ligations.

I would like to say further that we should heed what Dr. Luke had to say, and what he has put in the literature about the "new way of life." I think that every patient should be treated enthusiastically by conservative means, and only the failures should be treated surgically.

Dr. Linton, I am sure, treats some patients conservatively, but I think he has pointed up that where conservative treatment fails—and it may fail not because of the method of treatment, namely, the support and elevation of the foot of the bed, but because for some reason or other the patient cannot cooperate, or the doctor cannot get it across to the patient, or maybe the doctor doesn't know the proper way to instruct such patients—some of us have to resort to surgery in these patients. Very few patients actually come to deep vein ligation, and those that have deep vein ligation I believe also have to have ligation of those communicating and perforating veins. I do not think that the medical treatment, or the conservative treatment, is the whole answer, and I do not believe that deep vein ligation is the whole answer. I believe we must treat the individual patient; we must take the entire picture of the patient into consideration and do as indicated from what has transpired and from what we know about this syndrome.

The Problem of Perforator Localization in Varicose Veins

An Operation to Deal with Perforator Incompetence

THEODORE B. MASSELL, M.D.; E. CRAIG HERINGMAN, M.D., and SEYMOUR GREENSTONE, M.D., Los Angeles

Without doubt, the commonest disease in the field of angiology is varicose veins of the lower extremities. Inasmuch as this affliction is as old as the upright posture of the human race and is easily diagnosed, one should expect that its therapy would by now be well established and effective. Yet the treatment of varicosis has gone through numerous cycles, and surgical opinion is still not unanimous. This lack of enthusiasm for most of the operative procedures hitherto devised can be understood if one surveys the end-results of these procedures.[1-5] Some of the unsatisfactory results are due to obvious technical errors committed by inexperienced operators,[6,7] but even in the hands of well-qualified surgeons the late results of varicose vein surgery are generally unsatisfactory.

The chief cause for the recurrence of varicosis was pointed out by Sherman [8] as long as 12 years ago. He demonstrated that the usual tourniquet tests failed to detect most of the incompetent perforating and communicating veins. Furthermore, he found that about half of the incompetent perforators had no direct connection with the main saphenous trunks but emptied into secondary and tertiary tributaries. Thus, the ordinary vein-stripping operation leaves behind the smaller tributaries and their perforating vein connections. From these a new network of varices readily develops. Thus a logical approach to the therapy of varicose veins requires careful preoperative localization of the incompetent communicating and perforating veins and a surgical procedure in which these are interrupted.

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Clinical Criteria of Perforator Localization

Certain physical findings in the examination of the patient are of value in detecting and localizing the sites of the incompetent communicating and perforating veins. Patients who present any of the usual manifestations of venous stasis, such as ulcers, subcutaneous fibrosis, induration, and pigmentation, almost certainly have incompetence of these veins as well as of the superficial venous system. Furthermore, the offending perforators are to be found in or just proximal to the region in which the stasis changes are manifest. In areas where the tissues are of normal consistency the sites of the larger incompetent perforators may be detected by the palpation of fascial defects. These represent the openings through which these dilated veins pass through the fascia.

A third useful sign is the presence of one or more long tortuous superficial tributaries which seem to extend down from a major saphenous trunk and suddenly end on the lateral or anterior surface of the leg. Generally these "dead ends" occur directly superficial to the site of an incompetent perforating or communicating vein.

In contrast to the three criteria described above, our experience, which has been shared by others,[8,9] is that tourniquet tests, using either one or two tourniquets, are of

little help in perforator localization. The tourniquet aids in distinguishing postphlebitic varicosis from primary varicosis or in detecting gross incompetence of the short saphenous vein, but only very large, dilated communicating or perforating veins can be detected by tourniquet examination. These are always apparent by other, more reliable signs.

Phlebography for Perforator Localization

In 1948 a method was described for the localization of incompetent perforating and communicating veins by phlebography.[10] The technique originally described has been only slightly modified. The patient is placed in supine position on an x-ray table which is tilted so that the lower extremities are about 15 degrees below the horizontal. Soft rubber tourniquets are applied, respectively, to the ankle, just above the knee, and to the upper thigh. Injection is made percutaneously into any accessible vein on the foot. The ankle tourniquet obstructs the superficial venous system so that the opaque medium enters the deep venous system at ankle level. The popliteal and upper thigh tourniquets sufficiently impede the flow through the deep venous system so that the opaque solution flows out into the superficial system through the incompetent perforating and communicating veins. Such retrograde flow does not occur through the perforators with normally functioning valves. Thus, only the incompetent connecting veins are visualized.

In our last 42 phlebograms we have used diatrizoate (Hypaque, Winthrop-Stearns, Inc.). Twenty-five to thirty cubic centimeters of a 35% solution of this compound gives excellent opacification with a minimum of untoward local or systemic reactions.[11] As the injection is completed, the x-ray table is tilted back to the horizontal. Anteroposterior and lateral exposures are made of the leg. The popliteal tourniquet is removed, and x-rays of the thigh are made.

The appearance of the incompetent communicating and perforating veins is illustrated in Figures 1 to 5. From these photographs it is apparent that there is some variation in the x-ray appearance of

Fig. 1.—Two incompetent perforators in the thigh corresponding to Sherman's mid-Hunter canal and subsartorial perforators.

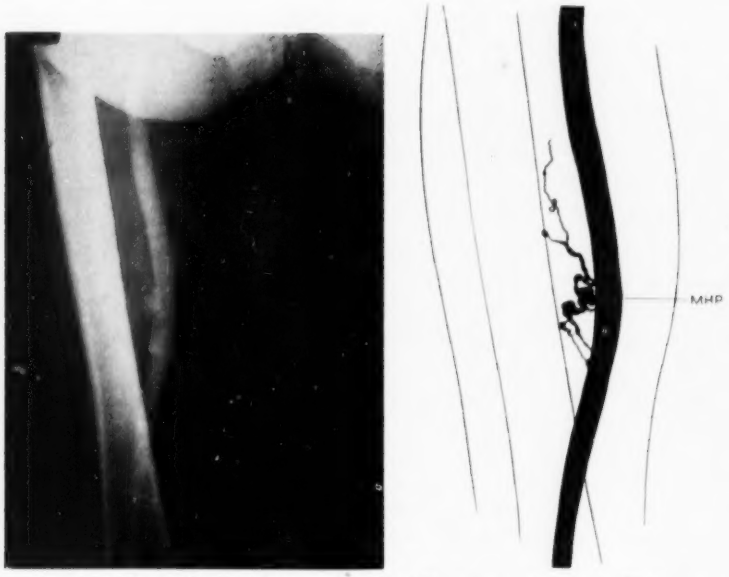

Fig. 2.—One large thigh perforator in the mid-Hunter canal region. This was not detected by clinical examination.

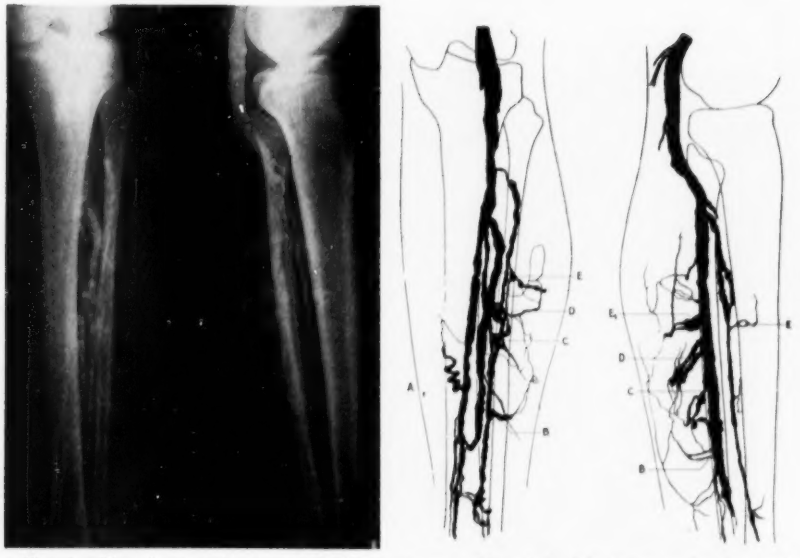

Fig. 3.—The short saphenous trunk is competent, although it fills down to its first valve. There is a large group of calf perforators. There is one medial perforator (*A*) visible in the anteroposterior view but not visible in the lateral view because it overlies the posterior tibial vein; (*E*) appears to be a single vein in the anteroposterior projection but is actually two separate perforators (*E*) and (E_1), running anteriorly and posteriorly, respectively.

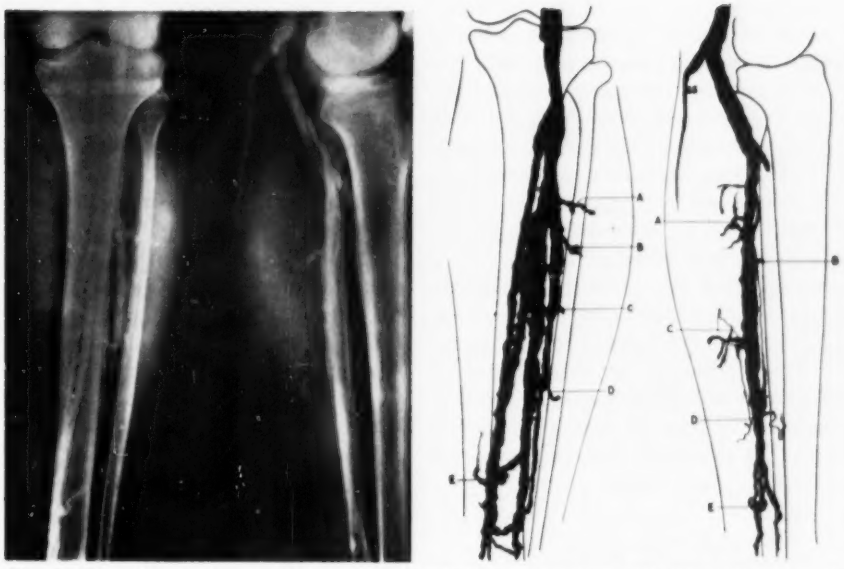

Fig. 4.—The short saphenous vein is grossly incompetent. The large perforator (*E*) was not detected on clinical examination.

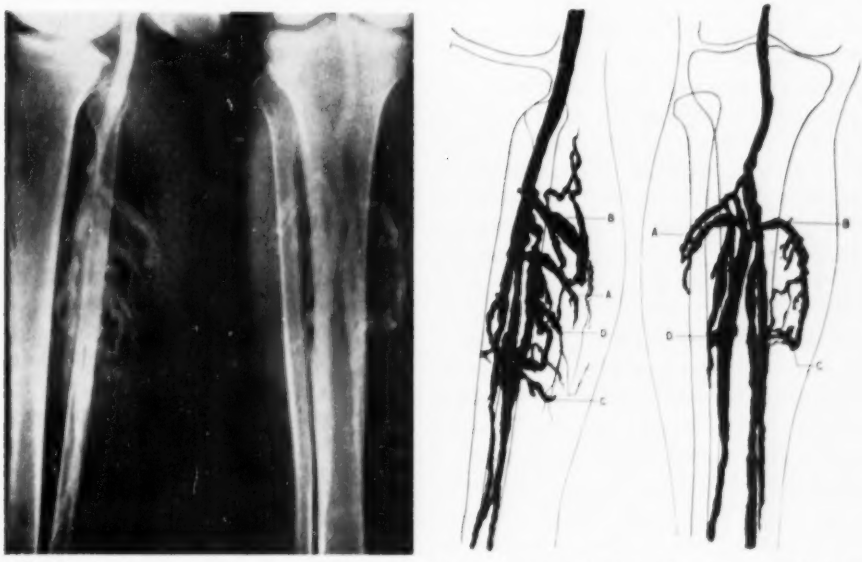

Fig. 5.—In this case all the incompetent perforating and communicating veins are accessible through a single longitudinal incision over the calf.

these veins. Some of the individual connecting veins may be followed from their deep veins of origin all the way into the superficial venous system. Other communicating and perforating veins are visible only a rather short distance from their origin. As Sherman's studies previously indicated,[12] very few of these incompetent veins occur in the thigh, but the overwhelming majority are below the knee.

By comparing the films of the anteroposterior and the lateral exposures, it is possible to obtain a three-dimensional projection and thus estimate with reasonable accuracy the location at which each perforator and communicator reaches the fascia. The comparison of the two x-ray views also allows one to distinguish ordinary tributaries of the saphenous trunks from the veins which connect with the deep system.

The suspected site of each incompetent perforating and comunicating vein is then measured from some fixed point, such as the tibial table. Finally, the localization by phlebography is checked against the previous clinical examination, the results by the two methods are correlated, and the details of the operation are planned.

The Operative Procedure: Radical Varicose Phlebectomy

There are three basic steps in the operative procedure.

(1) The first step is a conventional resection of the terminal portion of the saphenous trunk and its tributaries. (*a*) For the great saphenous, the usual oblique incision is placed in or above the inguinal fold so that the saphenofemoral junction is centered in the operative field. The saphenous trunk is divided between hemostats almost at once to provide easy exposure of the fossa ovalis and the external pudendal vessels. The cribriform fascia is dissected away so that the femoral vein can be clearly seen for 2 cm. above and below the entrance of the saphenous vein. Thus, subfascial tributaries may be detected and divided. (*b*) For the lesser saphenous a liberal transverse incision 3 or 4 cm. above the popliteal crease is used. The fascia is incised in the same direction, and the lesser saphenous vein is dissected right up to its junction with the popliteal vein.

(2) The distal saphenous trunks are exposed at malleolar level and divided. An intraluminary stripper is then passed upward, and the entire saphenous vein is avulsed, most often in a single segment. Occasionally the proximal end of the short saphenous vein is difficult to find because of its frequently aberrant location. In such cases, unnecessary trauma to the popliteal structures can be avoided by passing the intraluminary stripper up from below so that the saphenous trunk can easily be located by the palpable presence of the stripper.

(3) In the third step vertical incisions are made over the sites of the incompetent communicating and perforating veins. These incisions vary from 2 to 14 cm. in length and are planned so that each gives access to as many perforators as possible. Since the latter tend to occur in clusters, it is not unnsual to interrupt four or five of these veins through a single incision. In the thigh and proximal two-thirds of the leg the communicating and perforating veins are approached by incising and undermining the fascia. This subfascial approach makes it easier to find these veins and also assures the identification and division of the entire vein. Deep to the fascia the perforators are straight veins without tributaries, but just superficial to the fascial boundary they are often tortuous and receive tributaries which can easily be missed and left intact. In the distal one-third of the leg there are so many fibrous septa that a subfascial approach is not feasible. Here each perforator is traced down to the fascia. The fascial opening through which it passes is enlarged, and the vein is gently withdrawn and ligated so that the level of interruption is actually deep to the fascia.

The closure of the various incisions is carried out in layers. All the fascial openings are repaired with fine interrupted nonabsorbable (cotton) surgical sutures before the skin is sutured. Despite the need of meticulous care in handling the tissues, the operation on both extremities rarely requires more than two and a half hours if the short saphenous system is not involved. The time required for changing the position of the patient and performing a bilateral short saphenous stripping adds another 30 to 40 minutes to the length of the operation.

Active ambulation is started six to eight hours after the operation is completed, and the average postoperative hospital stay is two days. The period of disability seems little if any longer than that associated with vein stripping alone.

Results

The effectiveness of this approach to the problem of varicose veins has been studied in a group of 210 patients with varicosis in 318 limbs. Because of the difficulty in controlling the details of the surgical procedure in clinic or Veterans Administration patients, only private patients, operated on by one of us, were included. None of the patients in the study had previously had surgery for their varicose veins, and none were included who became pregnant after the vein operation.

Four different methods of approach were used in this series. In 61 extremities, which generally presented the severest degree of varicosis, the operation was planned on the basis of the correlated findings of clinical examination and phlebography. A second group, of 158 extremities, were operated after clinical localization of the incompetent veins. Phlebography was not used in this group, and they generally presented less severe varicosis than those in the first group. A very small third group consisted of 12 limbs in which there were significant but not severe varicose veins and in which there was no clinical evidence at all of perforator incompetence. All these were treated by stripping the long or short saphenous vein from malleolar level to its junction with the deep venous system. The fourth group, comprising 87 extremities, were treated by terminal saphenous resection alone. This was a rather heterogeneous group made up of (*a*) elderly or poor-risk patients who presented themselves with some complication of varicosis, requiring surgical intervention; the commonest of these complications leading to operation was acute ascending thrombosis in the varicosities; (*b*) young females with mild asymptomatic varices who were primarily concerned with the appearance of their legs.

The complications after each of these procedures are shown in Table 1. Despite the poor condition of the tissues in the extremities subjected to radical varicose phlebectomy — 45% manifested stasis changes, frequently associated with eczema or ulceration—and despite the greater number of incisions needed for the radical operation, the over-all incidence of postoperative complications was 14%, compared with 7% for terminal resection of the saphenous trunk alone. Actually there were more hematomas and wound infections in the latter group. The chief complication of radical varicose phlebectomy was sloughing of the edges of the incision in the distal leg. This occurred in nine cases, 4% of the limbs, and may well have been the result of too extensive fascial undermining. Postoperative edema was a problem after 5% of the radical and 2% of the conservative operations. Usually this was a persistence or exaggeration of swelling that was present prior to surgery. In

TABLE 1.—*Postoperative Complications*

Procedure	Total Pts.	Total Legs.	Preop. Stasis	Wound Inf., Hematoma	Wound Slough	F.B. Reaction	Thrombo-embolic	Persis. Edema	Nerve Injury	Total Postop. Complications	
										Number	Per Cent
Terminal resection of saphenous vein	59	87	18	4	0	0	0	2	0	6	7
Stripping without perforator dissection	10	12	3	1	0	0		0	0	1	8
Radical phlebectomy without phlebography	104	158	69	2	7	1	0	6	1	17	11
Radical phlebectomy with phlebography	37	61	28	1	2	2	1	5	0	11	18
Total, all procedures	210	318	118	8	9	3	1	13	1	35	

all but three extremities, it subsided within the first postoperative year.

Three instances of foreign body reaction were noted. In each case the offending cotton ligature was finally extruded and healing ensued. One patient had a zone of anesthesia comprising about 25% of the cutaneous distribution of the saphenous nerve. This was probably the result of the accidental severing of a major branch of the saphenous nerve during a perforator dissection in the medial calf region. Only one patient developed thromboembolism. He had been seen with a swollen leg and obvious superficial thrombophlebitis several weeks before surgery. Within a week after his varicose phlebectomy the patient had a return of the same symptoms in the same leg. A few days later he had a rather small but unmistakable pulmonary infarct. He was treated with anticoagulants, and there were no further embolic incidents. The nature and frequency of the postoperative complications after radical varicose phlebectomy hardly seem to justify Foote's belief that this type of procedure is too hazardous.[13]

For evaluating the late results, only those cases were used in which a follow-up was possible for a minimum of 18 months. The longest postoperative interval was seven years. About one-third of our cases had been operated within the last 18 months, and so these were eliminated. If the follow-up interval had been shortened to one year, the statistics for all the procedures would have been better, since few of the unsatisfactory results of varicose vein surgery were apparent in the first year after operation.

Despite our best attempts, some 15% of the patients were lost to follow-up, a few by death from unrelated causes but most of them by changes of residence. In all, some 114 patients, representing 239 limbs, were available for this study of the late results of varicose vein surgery.

For statistical purposes the following classification was adopted:

(1) Excellent result: trivial varicose veins or none at all, with complete absence of any of the preoperative symptoms or recurrence of signs of continued venous stasis.

(2) Good result: presence of a few varicosities of significant size but without any preoperative symptoms or recurrent signs of continued venous stasis.

(3) Unsatisfactory result: persistence or recurrence of symptoms or signs of venous stasis or of large numbers of varicosities.

The results according to these categories are given in Table 2. The difference in efficacy of the four different procedures is actually greater than the statistics indicate, because of the predominant type of case in each category. Thus, the patients who had preoperative phlebography almost all presented the severest degrees of varicosis, often with extensive stasis changes. Adequate therapy for these limbs seemed most difficult. Statistically, the patients who had radical varicose phlebectomy without preoperative phlebography seemed to fare as well as the former group. However, the phlebograms were omitted because the severity of the disease was less and clinical localization of the perforators and communicators seemed adequate. Had the clinical

TABLE 2.—*Results of Follow-Up (Eighteen Months to Seven Years)*

Procedure	Total Followed		Preop. Stasis	Excellent		Good		Unsatisfactory	
	Patients	Limbs		Number	Per Cent	Number	Per Cent	Number	Per Cent
Terminal resection of saphenous vein	38	52	16	10	19	11	21	31	60
Stripping without perforator dissection	5	7	3	2	29			5	71
Radical phlebectomy without phlebography	52	79	33	44	56	31	39	4	5
Radical phlebectomy with phlebography	19	31	12	16	52	14	45	1	3
Total, all procedures	114	169	64	72		56		41	

localization alone been sufficient, the end-results in this group should have been better, since the initial involvement was usually less extensive.

The apparently equal and obviously poor results both from terminal saphenous resection and simple stripping likewise need further interpretation. Several of the cases classified as "good result" in the terminal resection group were mild and relatively asymptomatic before operation, and so the full extent of the postoperative recurrence was not truly appreciated. With further follow-up most of these "good results" may well be reclassified as "unsatisfactory."

Comment

The presence of significant varicose veins after any of the procedures is interpreted by us generally to represent the persistence of one or more incompetent perforating or communicating veins. Some of these sites of incompetence were missed despite the localization by a combined clinical and phlebographic technique.

Phlebography, like other diagnostic types of radiography, is subject to error. At times all the opaque solution runs into one set of deep veins of the leg and fails to opacify the others. This situation is not related to the injection site or the position of the leg at the time of injection. A second injection sometimes results in visualization of the region which was not opacified by the first injection.

Errors in phlebography arise more often from difficulties in interpretation than from those in technique. It is usually easy enough to distinguish perforating or communicating veins from ordinary tributaries of the deep veins, but tributaries of the superficial venous system may be confusing when they overlie the major veins. The most difficult problem is to determine the site at which the perforators or communicators pass through the fascia. One of the advantages of a subfascial approach to these veins is that it allows for a reasonable margin of error in localization. On the other hand, in the distal leg, where the numerous fascial compartments render a subfascial dissection impractical, we have at times had the experience of being actually unable to find a grossly incompetent perforating or communicating vein which was clearly visible in the phlebogram.

Thus, it is likely that some of the incompetent perforating and communicating veins are not detected before operation, while others are detected but cannot be located at operation because of insufficient accuracy of the localization. As our experience has increased we seem to have reduced both these sources of recurrence, but there is still an apparently irreducible residue of error which we cannot obliterate.

Summary and Conclusion

A satisfactory result in the surgery of primary varicose veins is to be anticipated only if the incompetent perforating and communicating veins are interrupted. These incompetent connections may be detected and localized better by other clinical signs than by tourniquet examination. A still greater degree of accurate localization may be secured if the clinical examination is supplemented by x-ray phlebography.

The preferred operative procedure then includes the ligation and division of the incompetent perforators and communicators as well as the complete stripping of the incompetent saphenous trunks from malleolar level up. A subfascial approach is best for the connecting veins except in the distal leg, where the fascial compartments are small.

This procedure is not associated with an excessive number of postoperative complications, does not require prolonged hospitalization, and produces a high per cent of very satisfactory late results.

6317 Wilshire Blvd. (48).

DISCUSSION

DR. THOMAS T. MYERS, Rochester, Minn.: I congratulate Dr. Massell on his excellent presentation.

Apparently, his interest in this subject was stimulated by the same article, or the same man, Dr. R. S. Sherman, that aroused my interest. If you have not seen this article, which was published in the *Annals of Surgery*, August, 1949, you should read it.

In my experience, palpating the incompetent veins which perforate the fascia is the easiest and most valuable method of diagnosing them. If the examiner has a good understanding of the most likely location for these incompetent perforating veins, they can be located easily by palpating the defect in the fascia. Above the defect in the fascia a dilated vein is usually also palpable. My colleagues and I make this important examination in the office on the day that the patient is sent into the hospital. This is part of the process of marking the dilated veins to be removed at operation. The marking is done with a pyrogallic acid solution, which remains on the skin well. An X is placed over each incompetent perforating vein. Whenever the surgeon cannot be sure that a perforating vein is present but suspects the possibility, an X should be made at the site to indicate the need for exploration. The diagnosis will prove correct 95% of the time.

The most important and the most frequently encountered incompetent perforating veins are situated along the inner surface of the distal third of the leg and of the upper third of the calf and along the anterior surface and lateral surface of the upper third of the leg. The perforating veins on the inner and lateral surfaces of the foot are also frequently important, especially if the veins of the foot are dilated.

It is important to ligate all large incompetent perforating veins, but it is equally as important to remove all veins leading to or from them. I also close the fascial defect.

It is my belief that all varicose veins of the lower extremity should be removed and the practice of removing only the main channel, which is becoming prevalent, should be abandoned.

DR. J. CUTHBERT OWENS, Denver: We used to do venography on those patients having anomalous or bizarre patterns of varicose veins, until we reviewed our results and concluded that the benefit to the patient did not warrant the expense and possible complications.

Palpation of the venous segments, assisted by percussion or ballottement of these veins, allows the examiner to determine the size of the vessel, its course, amount of scarring, and number of incompetent perforators. Such examination followed by excision of these segments under direct vision decreases so-called "recurrences." As we all know, varicose veins are prone to have marked variations. Therefore, patience plus surgical curiosity at operation are required to eliminate these segments. Multiple vertical (except at popliteal space) incisions along the course of each segment at spaced intervals, plus dissection between the incisions, are rewarding in locating bizarre or anomalous veins. Stripping is a "blind" procedure and should be reserved for the uncomplicated varicose vein.

In the past three years, we have done almost 200 cases on an operating room-outpatient basis, using epidural or local anesthesia. Only six of these have required admission. Instruction for ambulation at home, plus mild sedation, is given to each patient. Our recurrences or missed veins have been around 5%. We do not mean to imply that excision of varicose veins is a simple operation, or that it is possibly an office procedure. In no instance have we felt that postoperative care was neglected; the few complications which have occurred could easily have developed even if the patient had been admitted to the hospital. The savings both to the patient and to the institution have been considerable, not to mention bed occupancy. The program for varicose veins has been so successful at Colorado General Hospital that we are now undertaking the same regimen at Denver General Hospital.

DR. THEODORE B. MASSELL: I want to thank the discussants very much. I particularly remember Dr. Meyer's splendid exhibit at the A. M. A. meeting, where I asked him how he finds perforating and communicating veins. He said, "That is the $64 Question"—that is, before it was $64,000.

But, apparently, Dr. Myers has a very sensitive palpating finger, which I very much envy. Several years ago I think our tendency was to do more phlebograms on varicose vein patients; then as time went on we thought we could localize these perforators by clinical examination alone. Recently, when I have had a chance to follow those cases in which we have had the help of the phlebogram and those in which we did not have that help, I found out that my finger is not anywhere near as sensitive as that of Dr. Myers. My clinical examination misses a lot of these perforators. Particularly in the bad cases with a lot of induration and wooden tissues, I cannot feel anything but a hard mass.

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Surgery Illustrated

Operative Injury to the Accessory Nerve in the Posterior Cervical Triangle

Comment upon the Abduction Test for Trapezius Muscle Paralysis

BARNES WOODHALL, M.D., Durham, N. C.

The superficial course of the accessory nerve in the posterior cervical triangle makes it peculiarly susceptible to injury during lymph node biopsy, removal of minor tumor masses, and similar operative procedures in this portion of the cervical axis. Paralysis of the trapezius muscle causes loss of true abduction of the arm above 80 to 90 degrees and diffuse shoulder girdle discomfort. The accessory nerve may be damaged by actual section or compression by ligature. Because of its inherent ability to show adequate functional regeneration, somewhat similar to that exhibited by other relatively pure motor nerves, such as the radial and facial nerves, suture or relief of the compression force at the point of nerve damage is strongly indicated in these injuries.

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From the Neurosurgical Division, the Duke Hospital and Duke University School of Medicine.

Clinical Example

A 15-year-old boy developed fever, malaise, and generalized adenopathy, three months before ad-

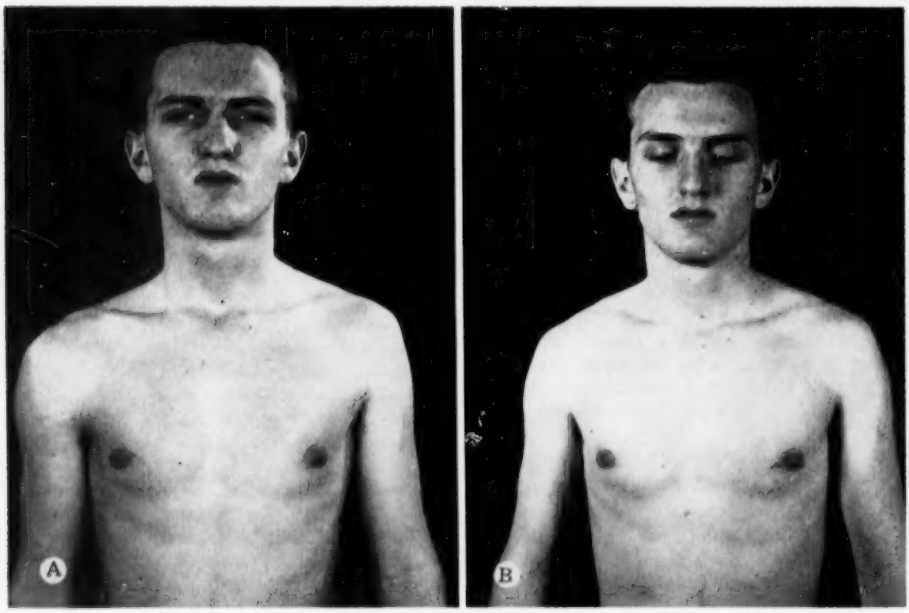

Fig. 1.—Neurological findings, motor. *A*, atrophy of superior third of right trapezius muscle and depression of right shoulder girdle as seen on Jan. 17, 1953. *B*, return of muscle mass and supportive function of this component of the trapezius muscle as noted on Dec. 3, 1953. The following preoperative and postoperative photographs were also made on these respective preoperative and postoperative dates.

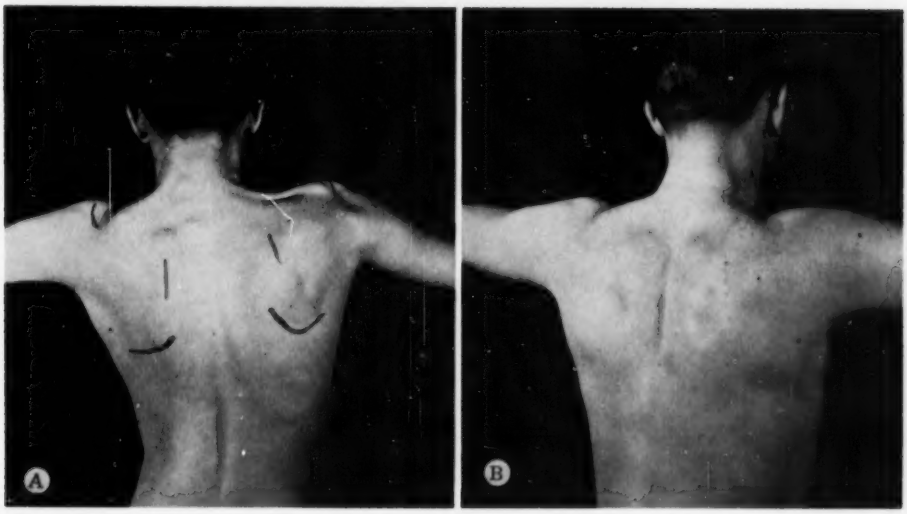

Fig. 2.—*A*, posterior view of atrophy of the superior third of the right trapezius muscle. Abduction in this patient was possible to 80 degrees before failure of scapular fixation precluded further abduction. *B*, restoration of muscle mass and normal support of scapula during early abduction movement to 90 degrees 11 months after operation.

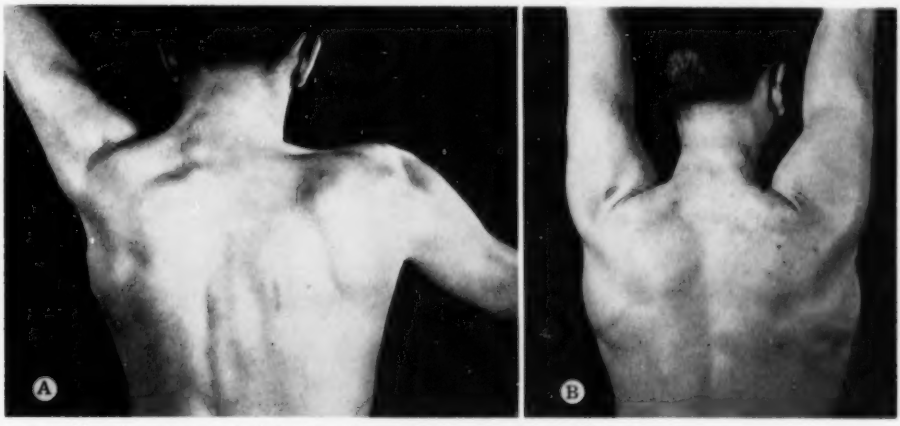

Fig. 3.—*A*, loss of abduction above 90 degrees on the right side. Elevation of the upper extremity, in both flexion and abduction, is accompanied by scapulothoracic movement. The part that the trapezius muscle plays in this rhythmic shoulder joint movement has been analyzed in detail. The upper third of the trapezius, the levator scapulae, and the upper digitations of the serratus anterior form a unit that passively supports the shoulder, actively elevates the shoulder, and forms the upper component necessary for scapular rotation. All three muscles exhibit an action potential while at rest, evidence for the postural function of this group. With abduction, the superior third of the trapezius shows an action potential that rises in a linear form with some current undulation in the curve at 90 degrees of abduction, where the support function of the muscle is changed to that of scapular rotation. The inferior third of the trapezius, with the lower four digitations of the serratus anterior, form the lower component of the scapular rotary force couple, and the trapezius portion is most active in abduction. The middle third of the trapezius functionally seems to fix the scapula in its plane of motion during abduction. When the trapezius muscle is paralyzed, the scapula fails of support and fixation and no fulcrum is available for the two components of the scapular force couple. True abduction then fails above 90 degrees, although the substitutive power of the serratus anterior allows elevation of the arm in flexion. *B*, normal abduction 11 months after operation.

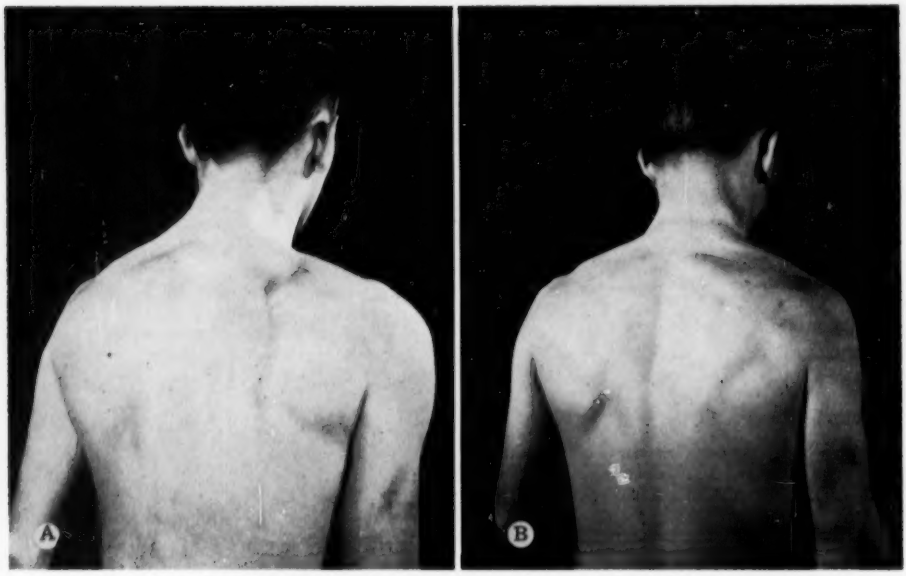

Fig. 4.—*A*, positive abduction test for accessory nerve paralysis, right. The small biopsy scar is visible behind the middle third of the right sternomastoid muscle. In the performance of this test of trapezius muscle dysfunction, the examiner holds the wrist firmly at the side. The patient then attempts abduction against this fixed point of resistance. A positive test indicating an accessory nerve lesion with trapezius muscle paralysis is illustrated in this patient, with flaring of the entire vertebral border of the scapula and a virtual dislocation of the scapula laterally upon the thoracic cage. Abnormal scapular rotation in complete trapezius paralysis, as well as in minimal involvement, may be demonstrated readily by fluoroscopy of scapular movement during the testing maneuver. *B*, normal or negative abduction test for trapezius paralysis, right, 11 months after operation.

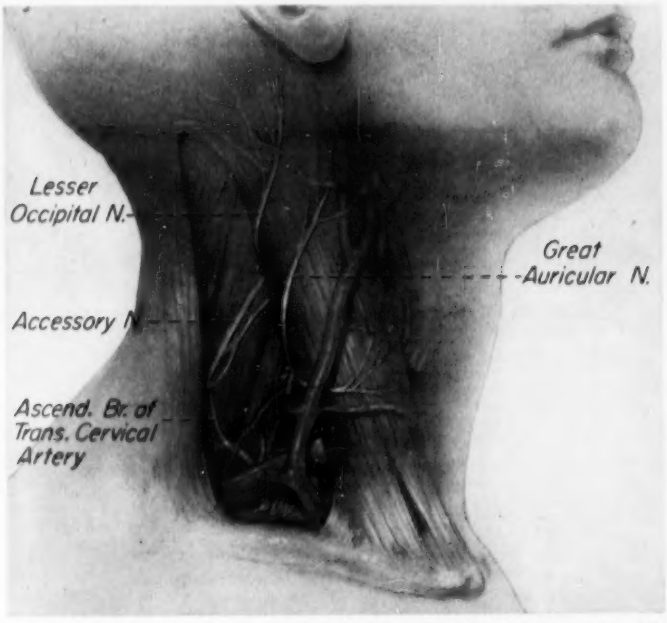

Fig. 5.—Surgical anatomy of the accessory nerve. In general, the upper third of the

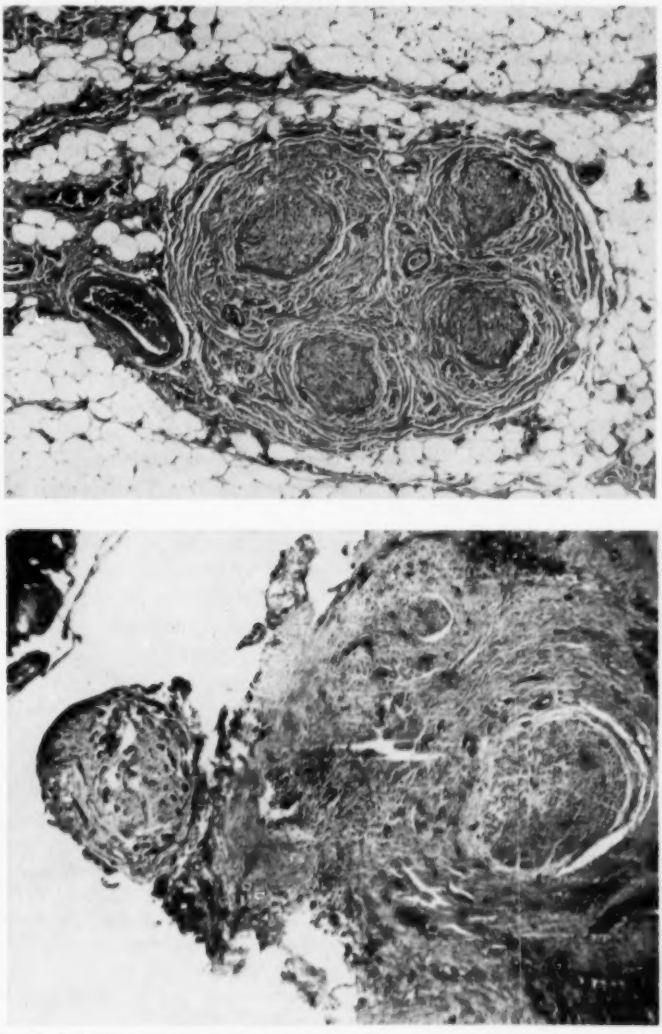

Fig. 6.—Pathological changes. Top, accessory nerve segment immediately distal to point of injury. Note size of degenerated nerve fascicles and concomitant vessel. Bottom, point of injury, with nerve fascicle imbedded in mass of scar tissue and foreign body reaction at edge of neuromatous area, representing circumferential suture. (Sections from case of complete nerve disruption.)

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trapezius muscle derives its major motor innervation from the eleventh cranial nerve, the spinal accessory, the lower two-thirds from the anterior rami of the upper cervical nerves. Overlap and variations from this historical and static concept of muscle innervation are common and are probably the result of variable migration of motor neurons. The vast majority of deliberate or accidental divisions of the accessory nerve are followed by clinical loss of function of the trapezius muscle. The accessory nerve as it emerges beneath the posterior border of the sternomastoid muscle lies very superficially in the posterior cervical triangle and remains just beneath the skin as it traverses this space to enter the substance of the trapezius muscle. Minor filaments may accompany the parent nerve trunk. It is a small nerve, measuring 3 mm. or less in diameter. A small arterial branch from the transverse cervical artery may accompany the nerve or closely approximate its course. During lymph node biopsy, control of this vessel has often implicated the accessory nerve segment by forceps or ligation injury.

mission to the Duke Hospital. A diagnosis of infectious mononucleosis was made on the basis of blood studies. On Nov. 16, 1952, biopsy of a lymph node in the right posterior cervical triangle was done, and, following this, loss of abduction of the right arm above 90 degrees was noted, with aching pain in the right shoulder girdle. Various aspects of this patient's neurological defect and subsequent course are illustrated in this paper by means of preoperative and postoperative photographs.

Accessory Neurological Findings—Sensory

Reference to the illustration concerning surgical anatomy shows the close relationship between the accessory nerve and certain sensory branches derived from the cervical plexus, chiefly the lesser occipital nerve. When the accessory nerve is injured at this point, close to the border of the sternomastoid muscle, patients may show sensory loss in the domain of the lesser occipital nerve and may complain of both numbness and paresthesias in this region of the posterior scalp.

Surgical Approach to Injuries of the Accessory Nerve

No instance of spontaneous regeneration of this nerve has been observed in this experience of 14 consecutive cases of operative injury. Exploration of this cranial nerve is conducted under the principles that govern peripheral nerve surgery in general. The surgical scar is usually short, transverse to the long axis of the neck, and thus at right angles to the anatomical course of the accessory nerve. It should be resected with Z-shaped skin incisions designed to expedite primary dissection of the proximal and distal nerve segments. The proximal segment is more easily found by using the posterior border of the sternomastoid muscle as a landmark and by keeping the dissection plane a very superficial one. Stimulation of the proximal segment will identify incomplete lesions, and the intact nerve fibers should be carefully dissected free from the operative scar; in such cases, a black nonabsorbable surgical (silk) suture about the nerve trunk may be found. Although there is considerable academic debate concerning the value of so-called neurolysis of incompletely damaged peripheral nerves, there is ample experimental evidence to show that nerve function is inhibited by nerve compression, and a circumferential suture represents real compression.

In complete cases, nerve gap is always small, 1 cm. or less, and the nerve segments are readily mobilized to overcome such a gap. Passive elevation of the shoulder, and use subsequently of a sling, will aid in suture without tension. After resection of the small proximal and distal neuroma and glioma, the suture is actually an approximation suture, done by one or two sutures of No. 5 ophthalmic silk. The arm should be supported by a sling for the following two weeks. Unless pain is associated with involvement of the lesser occipital nerve, these sensory fibers need no particular attention. Annoying paresthesias in the domain of this nerve are best treated by total lesser occipital nerve division.

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Metatarsus Primus Varus and Hallux Valgus

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In about 1934, several patients operated on for hallux valgus in the preceding few years began to appear with recurrence of deformity. The obvious common finding in all these patients was metatarsus primus varus. Other patients operated on during the same period and by the same method had satisfactory results. None of these had metatarsus primus varus. It was concluded that metatarsus primus varus was the primary deformity and that failure to evaluate its significance and to correct it was responsible for recurrence of hallux valgus.

To verify the above conclusions an x-ray study of normal asymptomatic feet was made. A group of employees in a large industrial plant were asked if they had ever had any foot trouble. If their answer was "no," x-rays of their feet were made. On completion of the survey it was apparent that not all were strictly frank, since there were nine in the group with obvious, rather marked hallux valgus.

A total of 374 feet in 178 persons were studied. Lines were drawn on the x-ray films following the long axes of the first and second metatarsals and the long axes of the great toes and the intermetatarsal and metatarsophalangeal angles measured. This method has since been employed by Stein,[1] Mitchell and co-workers,[2] Hardy and Clapham,[3] and others.

In 356 normal feet of the above group the intermetatarsal angles varied from 0 to 16 degrees. The metatarsophalangeal angles varied from 0 to 20 degrees. In the majority the metatarsophalangeal angles were about twice the intermetatarsal angles regardless of how narrow or wide. From this study it was concluded that the ideal normal foot (Fig. 1) is one in which the first and second metatarsals are parallel and the great toe extends directly forward in the long axis of the first metatarsal and that the average normal foot has a metatarsophalangeal angle of about 20 degrees and an intermetatarsal angle of about 10 degrees (Fig. 2).

It was further noted that the shape of the first cuneiform varied considerably from the textbook normal in 11% of feet. This seemed to occur more frequently and to a greater degree in those feet with wider-than-average intermetatarsal angles.

Similar measurements were made on the 18 hallux valgus feet. None of these had intermetatarsal angles of less than 10 degrees and they varied from 10 to 18 degrees, with the metatarsophalangeal angles ranging from 22 to 56 degrees. Also the degree of hallux valgus was again found to be about twice the degree of metatarsus primus varus. First cuneiform deformity was demonstrated in 47% of feet, as opposed to only 11% in the normal feet.

The significance of variation in the shape of the first cuneiform and obliquity of the cuneometatarsal joint was not immediately appreciated. It was thought that this might have been more apparent than real and perhaps due to the x-ray technique employed. After several trials it was determined that the best visualization of the first cuneiform and the cuneometatarsal joint could be obtained by projecting the x-rays at a right angle to the dorsum of the foot with the patient seated or standing and the foot resting horizontally on the x-ray cassette. All subsequent studies were made in this way.

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Upon completion of the above studies an operation was devised to accomplish correction of the metatarsus primus varus element of the deformity as well as the hallux valgus and has been employed with some variations and refinements since that time.

Fig. 1.—Ideal normal foot. First and second metatarsals are approximately parallel. The great toe projects forward in the long axis of the first metatarsal, and the cuneometatarsal joint is transverse.

Fig. 2.—Average normal foot. Note that the cuneometatarsal joint is transverse.

The study of hallux valgus and normal feet has continued and has confirmed the impressions gained in the initial study and has added some other significant facts. An additional group of 886 patients was studied. This group comprised 441 females and 445 males aged from a few months to 80 years. Both feet were studied in 260 females and 135 males. Since the patients in whom both feet were examined presented themselves for the most part with complaints referable to both feet, one can assume that functional foot disabilities are about twice as common in females as in males. Among the 395 feet of patients in whom both feet were studied there were 194 with hallux valgus or about 49%.

In the entire group of 886 patients one foot only was examined in 181 females and 310 males. These patients presented themselves chiefly because of trauma to one foot—hence the predominance of males.

Among 446 normal male feet studied (Table 1) it will be noted that 94% had intermetatarsal angles of 10 degrees or less and that 86% had intermetatarsal angles of 6 to 10 degrees, while among 228 normal female feet (Table 2) only 86% had intermetatarsal angles of 10 degrees or less, and only 81% had intermetatarsal angles of 6 to 10 degrees. Another striking finding was that parallel or nearly parallel first and second metatarsals (angles 0 to 4 degrees) occurred in 46, or about 9%, of male feet and in 15, or slightly more than 4%, of female feet.

In the entire group of male and female feet cuneiform deformity was present in 27%. However, it was present in only 3% of male feet and in 39% of female feet.

Among 77 hallux valgus feet in males (Table 3), 49% had intermetatarsal angles of 10 degrees or less, while 50% had intermetatarsal angles of more than 10 degrees. Among 341 female hallux valgus feet (Table 4), only 35% had intermetatarsal angles of 10 degrees or less, and 64% were above 10 degrees.

TABLE 1.—*Normal Feet in 466 Males* *

Age, Yr.	No. Feet	Intermetatarsal Angles, Degrees								
		0	2	4	6	8	10	12	14	16
0-5	19	10			6	3				
6-10	46	10			11	10	13	2		
11-15	60	7	3		11	15	22	2		
16-20	43	2			11	9	14	5	2	
21-25	43	2			14	13	10	4		
26-30	60	1		1	12	18	21	6		1
31-35	44	1	2		9	10	19	2		1
36-40	44	1		1	8	9	17	5		
41-45	24			2	5	9	7	1		
46-50	25	1		1	7	4	8	2		
51-55	22				3	6	10	3		
56-60	20	1			6	3	8			
61-65	9				3	1	4	1		
66-70	4					2	2			
71-75	2					2				
76-80	1						1			
Total	466	36	5	5	106	115	155	33	9	2
				94+%					5%+	
						86%+				

* The greatest number of feet with parallel or nearly parallel first and second metatarsals is in group up to 15 years of age; 94% of male feet have intermetatarsal angles of 10 degrees or less; 86% have angles of 6 to 10 degrees; 5% have angles of 12 to 16 degrees.

TABLE 2.—*Normal Feet in Females* *

Age, Yr.	No. Pts.	No. Feet	Intermetatarsal Angles, Degrees							
			0	4	6	8	10	12	14	16
0-5	8	10	7		1	1		1		
6-10	16	28	2	1	9	8	7	1		
11-15	27	45	1		8	12	20	4		
16-20	19	32		2	2	15	10	2	1	
21-25	13	19			4	4	9	2		
26-30	26	38			5	14	16	3		
31-35	19	29			5	5	9	9		1
36-40	22	26			7	6	6	4	1	2
41-45	17	21			5	7	8			1
46-50	24	35			2	13	16	3		1
51-55	18	22			3	6	10	2	1	
56-60	10	13			5	2	2	3	1	
61-65	5	8			2	1	3	1	1	
66-70	3	4	2		1	1				
75-80	1	1							1	
Total	228	331	12	3	59	95	116	35	6	5
					86%+				13%+	
						81%+				

* The greatest number of feet with parallel or nearly parallel first and second metatarsals is in group up to 15 years of age; 86% of female feet have intermetatarsal angles of 10 degrees or less; 81% have angles of 6 to 10 degrees; 13% have angles of 12 to 16 degrees.

TABLE 3.—*Hallux Valgus in Males* *

Age, Yr.	No. Pts.	No. Feet	Intermetatarsal Angles, Degrees									
			4	6	8	10	12	14	16	18	28	36
11-15	2	3				2		1				
16-20	3	5			2	2				1		
21-25	9	12		1	2	1	3	2	2	1		
26-30	10	15	1	1	2	4	4		2			1
31-35	4	6		1	2	1			2			
36-40	14	18		1		7	3	3	4			
41-45	7	9		1	3	2	3					
46-50	9	11		1	3	2		2	3			
51-55	7	12	1	2	1	1	2		3	2		
56-60	6	10		1	1	2	1	1	2	1	1	
61-65	3	4		1			3					
66-70	3	3			1		1		1			
Totals	77	108	2	10	17	24	20	9	19	5	1	1
					49%+				50%+			

* Slightly more than half of male feet with clinical hallux valgus have metatarsus primus varus, i.e., intermetatarsal angles of more than 10 degrees.

Cuneiform deformity was present in about 43% of hallux valgus feet of both sexes.

In the entire group (normal and hallux valgus) there were 80 girls and 102 boys under 19 years of age. There were 20 girls and only 3 boys with hallux valgus (Table 5). Among the four hallux valgus feet in boys, two revealed intermetatarsal angles of 10 degrees or more, while in 27 feet of girls, 18, or 66%, had metatarsus primus varus. Of the 31 hallux valgus feet in children, 28 exhibited cuneiform deformity.

Since all these children had worn the usual children's shoes, the high incidence of hallux valgus and astonishingly high rate of metatarsus primus varus cannot be explained except on the basis of inherent developmental factors.

In hallux valgus feet of both sexes and all ages the incidence of other congenital anomalies was much higher than in normal feet and is to be made the subject of another paper.

The foregoing observations seem to refute the assumption that in the majority of cases the deformity of the big toe joint is the important one and that only occasionally does hallux valgus develop secondarily and inevitably from congenital metatarsus primus varus.[4] On the contrary, they indicate that hallux valgus is in more than 50% of feet secondary to a congenital malformation of the first cuneiform bone which leads to or is concomitant with metatarsus primus varus. As the foot grows and develops, hallux valgus is increased by dynamic

TABLE 4.—*Hallux Valgus Feet in Females**

Age, Yr.	No. Feet	Intermetatarsal Angles, Degrees												
		4	6	8	10	12	14	16	18	20	22	24	26	28
0-5	2							1	1					
6-10	6		1	2		1	1	1						
11-15	19			2	2	7	5	2	1					
16-20	15		1	2	3	4	2	2	1					
21-25	19				2	2	4	9		1	1			
26-30	25		3	1	5	2	3	11						
31-35	35			3	15	3		9	3		1			1
36-40	30			9	5	5	2	6	3					
41-45	37		2	4	13	2	3	10	2	1				
46-50	46	1		4	7	5	3	14	5				1	
51-55	43		2	2	13	6	7	6	7					
56-60	37		2	3	5	12	2	7	2	4				
61-65	18			1	2	4	2	3	2	2	2			
66-70	10				2	1	1	1		4		1		
71-75	4			2	1	1								
76-80	1							1						
Totals	341	1	11	35	75	55	35	83	27	12	4	1	1	1
			35%+							64%+				

* Sixty-four per cent of female feet with clinical hallux valgus have metatarsus primus varus, i.e., intermetatarsal angles of more than 10 degrees.

TABLE 5.—*Hallux Valgus in Children**

Age, Yr.	Females, 19				Males, 4			
	One Foot Studied	Both Feet Studied						
		Bilateral		Unilateral	Bilateral		Unilateral	
		Intermetatarsal Angles, Degrees						
5		8	16					
8		8	8					
10	16			14				
				6				
				12				
11	12							
12	14	8	10					
		10	12					
		16	16					
13	14							14
14	14	12	12	14				
15		12	12	14	10	10		
16		18	16					
17		10	6					
18					14	10	10	
Total Patients	5	9	9	4	2	2	1	1

* Each rectangle represents one patient. In 33 feet studied in 23 patients, 13, or 29% +, had metatarsus primus varus, i.e., intermetatarsal angles of more than 10 degrees.

intrinsic and extrinsic forces applied to the great toe.

The etiological relationship between metatarsus primus varus and hallux valgus has been noted by several observers but has not been sufficiently stressed and not thoroughly understood. Testimony of this assertion lies in the number and diversity of procedures for the correction of the deformity which are illogical or which are directed at overcoming secondary factors, such as abnormal muscle pull, rather than the primary deformity. Once the primary deformity is corrected, unbalanced muscle action is no longer a deforming factor unless anomalous tendon insertions are present.

Ewald,[5] in 1912, noted obliquity of the distal articulation of the first cuneiform in hallux valgus feet. Berntsen[6] verified Ewald's observations in 1930 and recorded cuneiform deformity in 67% of hallux valgus feet but in only about 6% of normal feet. Recently (1954) Haines and McDougall[7] have again called attention to cuneiform deformity as part of the pathological anatomy of hallux valgus.

The operation herein described was devised to attack the primary deformity as well as the hallux valgus and is based on the work of Truslow[8] and Peabody. Hallux valgus and metatarsus primus varus are deformities in every way comparable to coxa vara and genu valgum, which, if occurring in the same extremity, would be corrected by two osteotomies (Fig. 3).

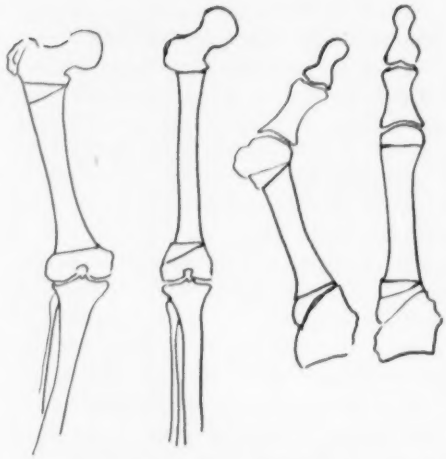

Fig. 3.—Two osteotomy concepts of correction of coxa vara and genu valgum in the same extremity and hallux valgus and metatarsus primus varus in the same foot.

The Operation in Detail

The first part of the operation consists in the correction of the hallux valgus element by the method of Peabody, which in the main consists of removal of the exostosis followed by cuneiform osteotomy of the neck of the metatarsal. A wedge of bone with its base medial and wide enough to permit correction of the valgus position of the metatarsal head is removed, and the capsule is sutured taut to the metatarsal neck to hold the great toe in alignment with the long axis of the metatarsal.

To the foregoing the following has been added. The incision is extended proximally to the midportion of the first cuneiform bone and is carried down to bone along the base of the first metatarsal and cuneiform, from which capsule and periosteum are stripped on the dorsal and ventral aspects. This mobilizes the base of the metatarsal. The joint can then be opened by pulling the metatarsal laterally with a small bone hook. The lateral ligaments act as a hinge. While the metatarsal is held as nearly parallel with the second as possible, a bed is prepared for the reception of a bone graft by removing portions of the articular surfaces of the cuneometatarsal joint with an oscillating plug cutter. This hole is made about half the thickness of the base of the metatarsal. A circular graft of correct size is cut from the preserved exostosis if it is large enough or from the upper end of the tibia or from a piece of banked bone. We prefer autogenous grafts but on occasion have used banked bone. This graft is impacted into the prepared bed. The remaining dead space in the joint is filled with small chips of bone from the exostosis and from the wedge from the distal end of the metatarsal removed in

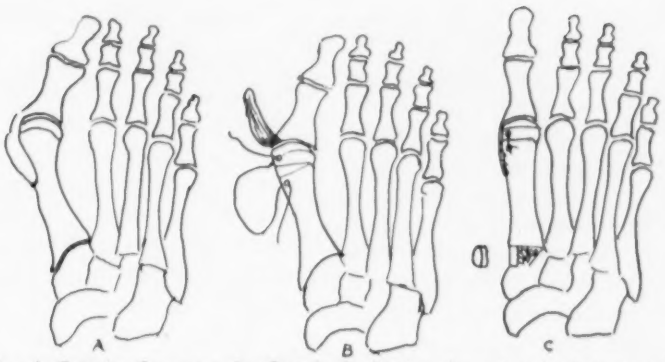

Fig. 4.—*A*, Capsular flap cut and reflected. *B*, distal wedge cut and suture passed through drill holes. *C*, hallux valgus corrected and cuneometatarsal joint fused with circular prop graft and bone chips.

the first part of the operation. The circular graft acts as a prop to hold the first metatarsal in corrected position. No fixation of the graft other than suture of the capsule over it is necessary because it is locked securely in position by the tendency of the metatarsal to spring back into a position of varus. The wound is then closed in the usual way and medial and plantar tongue depressor splints are applied to the side of the foot and big toe with narrow elastic bandage. Casting is unnecessary.

When this procedure was first done, the wedge of bone removed from the distal end of the metatarsal was used to insert into a transverse osteotomy at the base of the metatarsal (Fig. 4). Often it was too thin, complete correction of the metatarsus primus varus was not obtained, and the graft because of its shape tended to be extruded from the osteotomy. When the significance of the role of cuneiform deformity began to be appreciated, fusing the joint by denuding its surfaces of cartilage and inserting the wedge was done but presented the same objections as above. Then a rectangular graft of cortical bone was used quite satisfactorily but was difficult to cut to proper size. Since circular plug cutters have been used to prepare a bed and cut a graft, the above difficulties have been completely eliminated and the operation done more rapidly and with greater ease.

It is logical to fuse the cuneometatarsal joint much the same as in the Hoke, Miller, Lowman, and other procedures for flat foot. Most patients with hallux valgus have weak feet. Fusion of the cuneometatarsal joint aids in the solution of the over-all problem by adding stability to the medial border of the foot. Furthermore, insertion of a graft in the medial side of the joint is a positive and logical method of holding the first metatarsal in correct position in contrast to any procedure aimed at fusing the lateral side of the first metatarsal base to the second.

The first metatarsal is not shortened in this operation. If it is short, as it was in 40% of our patients, it can actually be lengthened by using a larger graft. While there is some difference of opinion as to the clinical importance of a short first metatarsal, it would seem ill advised to do any operation for hallux valgus which would result in further shortening of an already short first metatarsal (Fig. 5*A* and *B*).

Postoperative Care

Patients are permitted up-and about as soon as they desire. They are able to walk on the outer borders of their feet and heels without much difficulty. The splints and sutures are removed in two weeks. Night splints are provided to hold the great toes in proper position in those instances when the great toe tends to relapse into valgus. In three weeks full weight-bearing in a cut-out shoe with sponge rubber longitudinal and metatarsal inlays is permitted. These

inlays are placed according to tracings and measurements of the feet. They should be fitted by the surgeon and not by a shoe salesman or appliance maker. As soon as all swelling subsides, the patient is fitted with regular shoes provided with the same type inlays. These are worn indefinitely. The importance of attention to the over-all problem of the feet in each patient cannot be too strongly emphasized. Neglect of this phase of treatment will inevitably result in a dissatisfied patient.

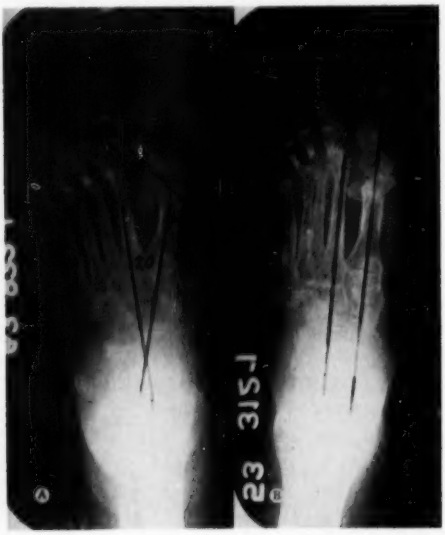

Fig. 5.—Rheumatoid arthritic foot with marked hallux valgus and metatarsus primus varus before and after operation. Note bone graft in place and complete correction of metatarsus primus varus.

Complications

There have been no serious complications. There has been occasional delay in skin healing as is common on the feet especially when incisions traverse thickened skin. There was one benign wound infection in the entire group. The most frequent complication, if indeed it can be so called, has been persistent swelling, which may delay fitting of regular shoes for several weeks. This swelling has been difficult to explain, since it has often occurred in one foot of a bilateral case when the same operation has been done on both feet.

Follow-up

A total of 159 feet in 83 patients have been operated on. In some of the patients operated on in the early days of the development of the operation there were several recurrences of mild hallux valgus due to incomplete correction of metatarsus primus varus or slight loss of correction from slipping of the wedge-shaped graft. One of these patients was reoperated on with a satisfactory result. There have been no recurrences of hallux valgus in the later cases. A few patients were lost to follow-up shortly after operation, and the results are not known but were satisfactory when last seen. Only five patients in the entire series were followed less than three months. All others have been followed long enough to evaluate end results. Forty-one patients have been followed one year or more, many of these for several years. The longest follow-up was 18 years.

There were three instances of nonunion of the cuneometatarsal joint. Clinically these joints seemed solidly fused and were not producing any symptoms, but fusion could not be demonstrated by x-ray. There were no instances of nonunion of the distal osteotomy. Several patients with marked hallux valgus and rheumatoid arthritis had considerable limitation of motion of the big toe joint, but all were much more comfortable than before operation. There was no loss of push-off power of the great toe in any other patients, although a few had slight limitation of big toe joint motion.

It is difficult to classify end results of this type of operation in the usual way. As far as correction of deformity is concerned, the only failures were those mentioned above, and those were due to technical errors. With one exception the patients were satisfied, and this one was reoperated on. Subjectively all patients who were followed longer than three months were well pleased, so much so that they constitute the most grateful group in this writer's practice.

Summary and Conclusions

Results of a radiological anatomical study of several hundred normal and hallux valgus feet are presented.

Functional foot disabilities are much commoner in females than in males.

Average normal first metatarsal varus is 10 degrees.

Intermetatarsal angles wider than 10 degrees are commoner in females than males.

Cuneiform deformity and increased obliquity of the cuneometatarsal joint is commoner in females than in males and is commoner in hallux valgus feet than in normal feet.

Metatarsus primus varus and cuneiform deformity are present in well over 50% of hallux valgus feet, are probably primary deformities, and represent arrest of ontogeny.

If in a hallux valgus foot the intermetatarsal angle is 10 degrees or more and/or if first cuneiform deformity is present, the metatarsus primus varus element should be corrected.

An operation for correction of hallux valgus and metatarsus primus varus is presented and end results described.

Dr. Harold H. Gay, Medical Director, Dow Chemical Company, obtained the initial series of x-ray films.

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The Use of Potassium Chloride for Defibrillation of the Ventricles of the Hypothermic Dog

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While anoxic hearts of normothermic dogs can be uniformly defibrillated by a single 220 v. shock of 0.10 second duration, defibrillation by the same technique is not so readily accomplished in hypothermic dogs, as shown by previous studies in this laboratory [1,2] (Table 1). Defibrillation by repeated shocks was always possible, however, and an effective heart beat was restored in all instances, though not without difficulties in some.

TABLE 1.—*Result of a Single Shock of 220 Volts for 0.10 Second*

Temperature, C	Dogs, No.	Defibrillated, Normal Heart Beat	Defibrillated, Persistent Asystole	Not Defibrillated
26	20	10	6	4
24	4	2	1	1
23	4	2		2
22	3	1	1	1
20	4		1	3
Total	35	15	9	11

Swan and co-workers,[3,4,5] found "that the fibrillating hypothermic heart could rarely be converted to a normal rhythm by massage and electric shock. However, when the coronary arteries of the fibrillating heart were perfused with potassium chloride (1 mEq. per ml.) the fibrillation could usually be converted directly or by use of electric shock."

The object of this experiment was to compare the effectiveness of potassium chloride and electric shock in defibrillating the hearts of hypothermic dogs.

Experimental Methods

Mongrel dogs were anesthetized with pentobarbital sodium (25 mg/kg.). An endotracheal tube was inserted, and 100% oxygen was given with intermittent positive pressure by respirator. The animal's trunk was packed in crushed ice surrounded by plastic sheeting until the rectal temperature fell to 27 C (80.6 F). After removal of the ice the temperature usually fell another 2 C (3.6 F). Thoracotomy was performed through the left fifth intercostal space, and the pericardium was opened widely. Ventricular fibrillation was induced by an electric shock, usually 10 v. for 0.5 second. Occasionally, serial shocks of the same magnitude were required. Ventricular fibrillation was allowed to continue for four minutes without treatment. Manual cardiac compression was then started at a rate of 80 beats per minute. After two minutes, at which time the myocardium appeared pink and the fibrillatory movements were vigorous, a Crafoord clamp was placed across the ascending aorta and potassium chloride in a concentration of 1 mEq. per cubic centimeter was injected into the aorta proximal to the clamp. Four cubic centimeters (4 mEq.) was injected in the smaller dogs (8-10 kg.), and seven cubic centimeters (7 mEq.), in the larger dogs (15-20 kg.). The average injection was about 5 cc. (5 mEq.). The heart was compressed 15 times with the clamp in place to perfuse the coronary arteries thoroughly. This always stopped the fibrillation promptly and completely. The heart was completely arrested and motionless in diastole. The Crafoord clamp was then removed, and manual compression was resumed at the rate of 80 beats per minute. Sometimes a normal sinus rhythm began almost immediately. If not, and if the heart beat seemed ineffective after three to four minutes of cardiac compression, the root of the

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From the Harrison Department of Surgical Research, Schools of Medicine, University of Pennsylvania.

aorta was again clamped and 2 to 4 mEq. of $CaCl_2$ (1 mEq. per cubic centimeter) was perfused through the coronary arteries. This was done in nine dogs. In eight of these, ventricular fibrillation recurred. Potassium chloride was again used for defibrillation, and the alternate administration of KCl and $CaCl_2$ was often continued for a considerable period of time in an effort to obtain an effective heart beat. Epinephrine (0.1 to 0.5 mg. in a 1/10,000 solution) was injected into the left ventricle in some instances, and it appeared to produce about the same results as calcium chloride. Resuscitative measures were continued for at least an hour before giving up on any dog. When it appeared that a persistent, effective heart beat had been obtained, the chest was closed in the usual manner and the animal was rewarmed.

In using KCl for defibrillation in other experiments, it appeared that there was a higher percentage of good results when the period of fibrillation was not so long. In an attempt to confirm this observation, eight dogs were treated in exactly the same manner except that the coronary arteries were perfused with potassium chloride after only 1.5 to 2.0 minutes of ventricular fibrillation. Fibrillation was promptly abolished, as before. In seven instances, fibrillation recurred and repeated use of KCl, $CaCl_2$, and epinephrine as described above was required.

Results

The results are summarized in Table 2 and are compared with those of a series treated identically except that repeated electric shocks were used for defibrillation.

TABLE 2.—*Comparison of Defibrillation Methods*

Method	Dogs, No.	Defibrillated, %	Effective Heart Beat Restored, %
Serial electric shock after 4 min. of fibrillation	35	100	100
KCl after 4 min. of fibrillation	21	100	57
KCl after 1.5 to 2.0 minutes of fibrillation	8	100	87

Comment

In previous studies we obtained what we consider to be rather clear-cut information regarding the effectiveness of electric shock in defibrillating the hearts of normothermic and hypothermic dogs following a period of anoxia. This information was useful in providing a base-line for the present study.

Potassium chloride appeared to be effective in stopping ventricular fibrillation. It was not more effective than electric shock, however, and did not appear to have any outstanding advantage, such as ease of use. It did appear to have one serious disadvantage, i. e., cardiac arrest in diastole which tended to persist, apparently as a result of depression of myocardial activity. There was some difficulty in reestablishing an effective heart beat in every instance, and not uncommonly the outcome seemed to be in doubt for a half hour, or more.

As a result of these experiments, we are strongly inclined to favor electric shock rather than KCl when ventricular fibrillation occurs as a complication of hypothermia. We would not recommend the use of KCl under the conditions described above unless some more effective antagonist can be administered to aid in reestablishing an effective heart beat.

Conclusions

Both serial electric shock and potassium chloride are uniformly successful in stopping ventricular fibrillation in hypothermic dogs. The diastolic arrest which follows KCl administration is nearly always difficult to overcome.

When ventricular fibrillation is allowed to persist for four minutes before resuscitative measures are instituted, an effective heart beat can be restored in 100% of the animals after electric shock defibrillation but in only 57% after KCl defibrillation. When KCl is used after only 1.5 to 2.0 minutes of fibrillation, an effective heart beat is restored in 87%.

3400 Spruce St. (4) (Dr. Kirby).

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A Comparison of the Tissue Reactions to Plastic Materials

Dacron, Ivalon Sponge, Nylon, Orlon, and Teflon

CAPT. J. HAROLD HARRISON (MC), U. S. Army; DAVID S. SWANSON, M.S., Denver, and LIEUT. COL. ARTHUR F. LINCOLN (MC), U. S. Army

In the past decade there has been an increase in the use of plastics in surgery as suture material, for drains, as a replacement of bones and soft tissue defects, and, more recently, as blood vessel grafts. Some of the observers state that these synthetic materials are inert and incite no tissue reaction,[2,7,16,22] while others have reported reaction of varying degrees.[3,15,21,23] An evaluation is difficult because the response of the host will depend upon the site of implantation, degree of blood supply, motion, and the quantity of material implanted. The importance of removing the irritating plasticizers used in the manufacturing process has been previously emphasized.[15,23]

This paper represents a comparative study, under essentially the same conditions, of the tissue response to plastics that are being used commonly today.

Method

All the materials were washed thoroughly and boiled in a detergent solution, then rinsed and boiled in water. One-centimeter squares of a weave of polyethylene glycol terephthalate (Dacron), nylon, a polymer of acrylonitrile (Orlon), tetrafluoroethylene polymer (Teflon), and compressed polyvinyl (Ivalon) sponge were implanted in the subcutaneous tissue of the abdominal wall of nine dogs (Fig. 1). The implants were held in place with sutures of the same material with the exception of polyvinyl sponge, which was sutured with nonabsorbable surgical (silk) sutures. Meticulous tissue handling and hemostasis were employed throughout, and all the implants were placed well away from the suture lines.

Animals were given penicillin and streptomycin for seven days. They were followed clinically and killed at intervals of one week for eight weeks.

The implants were examined grossly, then excised with a margin of surrounding tissue and placed in 10% formalin. Paraffin-embedded tissue blocks were sectioned and stained with hematoxylin and eosin for microscopic study.

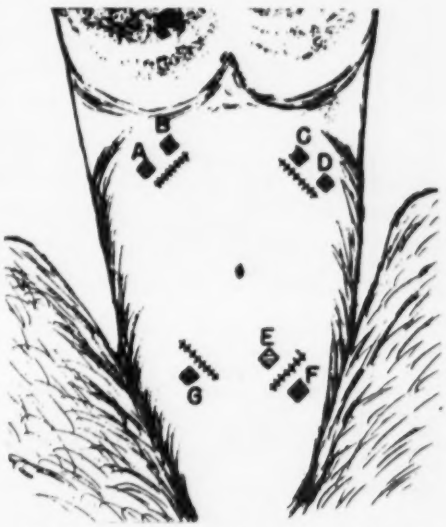

Fig. 1.—Schematic drawing of sites of insertion of implants. *A* and *B*, nylon; *C* and *D*, Dacron; *E*, Orlon; *F*, Teflon; *G*, polyvinyl sponge.

In a group of 20 dogs, 4 cm. squares of nylon and Teflon were placed in defects created in the pericardium. These animals were killed at varying intervals for 10 months and studied in the same manner.

Grafts of each of these materials were inserted into defects in the thoracic and abdominal aortas of dogs. These animals were killed at intervals up to one year and similarly studied.

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From the Research and Development Service, Fitzsimons Army Hospital, Denver.

Results

Nylon.—During the first three days there was edema surrounding the subcutaneous implants, with sufficient fluid in some to necessitate drainage. This subsided after approximately 14 days. The implants could be easily separated from the edematous surrounding tissue during the first 10 to 14 days. Microscopically (Fig. 2), there was an early marked acute inflammatory reaction characterized by an infiltration of polymorphonuclear leukocytes and macrophages. The acute reaction gradually subsided, leaving a chronic inflammatory reaction characterized by lymphocytes, plasma cells, macrophages, and foreign body giant cells. This diminished over a period of six months, after which there could be found only an occasional macrophage and foreign body giant cell. Fibrosis was evident on the 7th day, and the implant became completely encapsulated by proliferating fibrous tissue by 14 days. Growth occurred through the interstices of the weave at three to four weeks, with an eventual isolation of the individual fibers by six to eight weeks. A similar de-

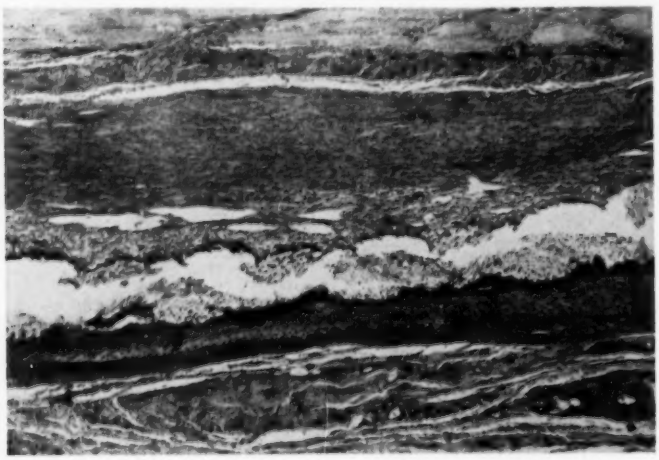


Fig. 2.—Photomicrograph of nylon implant—50 days; reduced about 2/5 from mag. × 75.

Fig. 3.—Photomicrograph of nylon pericardial implant at five months. Separation of fibers due to sectioning; reduced slightly from mag. × 75.

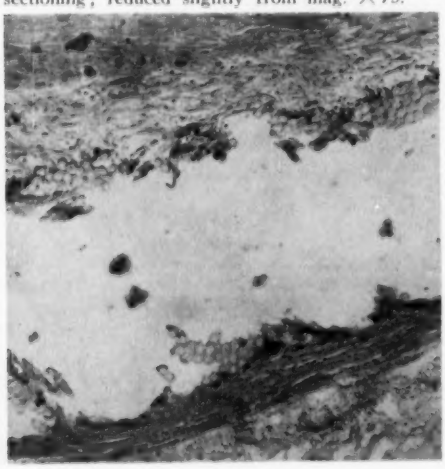
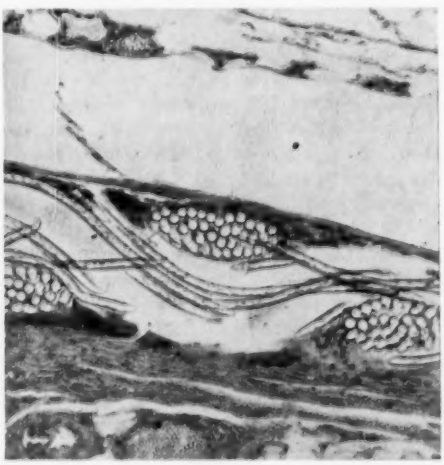


Fig. 4.—Photomicrograph of Dacron implant—50 days; reduced slightly from mag. × 75.



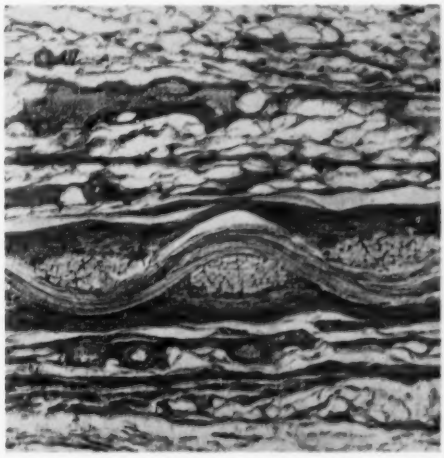


Fig. 5.—Photomicrograph of Orlon implant—50 days; reduced slightly from mag. × 75.

Fig. 6.—Photomicrograph of polyvinyl sponge implant—50 days; reduced slightly from mag. × 75.

gree of reaction occurred when the implants were placed in defects of the pericardium and blood vessels. At five months (Fig. 3) the pericardial implants were enclosed in matured fibrous tissue and only an occasional chronic inflammatory cell was present.

Dacron.—The edema elicited by the Dacron implants was slightly less than with nylon and subsided at the same rate. Microscopically, the acute reaction was of the same degree as with nylon. The chronic foreign body reaction was characterized by an infiltration of macrophages, foreign body giant cells, plasma cells, and lymphocytes, and it was less than with nylon (Fig. 4). There was reaction of a similar degree to Dacron inserted as artery grafts. The degree and rate of fibrous enclosure of the implants was the same as with nylon, while that surrounding the artery grafts was less.

Orlon.—In two of the eight animals there was edema surrounding the orlon implants, which subsided after seven days. Micro-

Fig. 7.—Photomicrograph of Teflon implant—50 days; reduced slightly from mag. × 75.

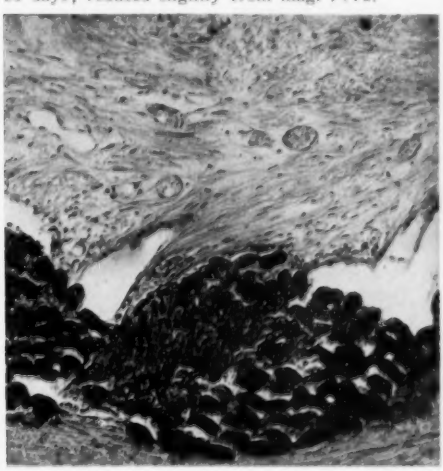
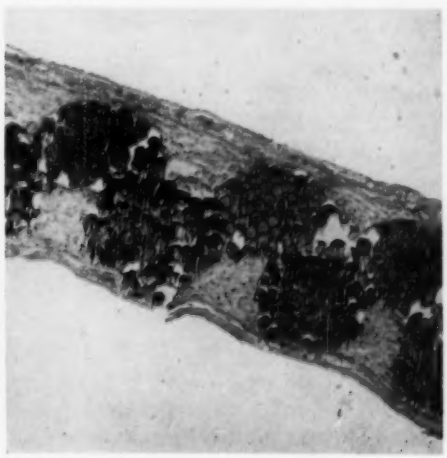


Fig. 8.—Photomicrograph of Teflon pericardial implant at four months; reduced slightly from mag. × 75.



scopically (Fig. 5), the acute and chronic inflammatory reaction and extent of fibrosis were less than with either nylon or Dacron.

Polyvinyl Sponge.—Grossly, the early reaction was similar to that elicited by Dacron and nylon. Microscopically (Fig. 6), the acute and chronic inflammatory reaction and fibrosis surrounding the polyvinyl sponge implants was of the same degree as that noted with Dacron. It was noted, however, that in the interstices of the polyvinyl sponge there was early a marked infiltration of polymorphonuclear leukocytes and round cells, and later macrophages and foreign body giant cells.

Teflon.—Grossly, there was no edema surrounding the Teflon implants. Microscopically (Fig. 7), though, an acute and chronic foreign body reaction was observed; it was considerably less than with the other materials. The implants became enclosed in a fibrous tissue capsule which was thinner and more pliable than that surrounding the other plastics. A similar minimal degree of reaction and fibrosis was observed surrounding the pericardial (Fig. 8) and artery grafts.

Silk was used for suturing the polyvinyl sponge implants, the pericardial grafts, and the artery grafts. In all instances there was more marked acute and chronic foreign body reaction surrounding the silk sutures than the synthetic materials.

Comparison of Tissue Response to Synthetic Materials

Material	Degree of Reaction	
	Acute	Chronic
Nylon	++++	++++
Dacron	++++	+++
Polyvinyl sponge	+++	+++*
Orlon	++	++
Teflon	+	+

*See discussion in text. Reaction surrounding polyvinyl sponge was similar to that found with Dacron, but there was a greater degree of both acute and chronic inflammation in the spaces within the material.

In the over-all comparison there was a marked difference in the response of the hosts to nylon and Teflon. Of the plastics studied, nylon caused the most inflammatory reaction and Teflon the least. There was an intermediate degree of reaction to Dacron, polyvinyl, sponge, and orlon, in that order (Table). The difference in the reaction to the latter in many instances was of a degree brought out by an over-all comparison of the gross and microscopic findings.

Comment

The reaction to a foreign material depends upon its chemical composition, the physical properties, and the area of surface coming in contact with the surrounding tissues. When used in small amounts, as in sutures, a small difference in reaction may not be apparent. When larger quantities are used, however, as in the replacement of various defects in the body, this factor is multiplied greatly and might well influence the outcome.

Jacoby demonstrated a chemical attraction for macrophages to a foreign material.[12] It has been shown that the amount of tissue reaction and damage encountered with implanted metals is equivalent to the degree of electrolytic activity produced when they come in contact with the body fluids.[25] The degree of tissue reaction and destruction produced by any synthetic material should be related to the degree of breakdown when it is subjected to body fluids and to the toxicity of the breakdown products.

The importance of interfacial tension and ability to be wet by water has been stressed by LeVeen.[15] Phagocytes must become adherent to the surface of foreign materials before they can ingest them.[6] In addition, Fenn has demonstrated that carbon particles in contact with serum are phagocytized more rapidly than when they are suspended in saline.[5] It is felt that the adsorption of protein on the surface of the plastic alters the molecular configuration from that of the adjacent tissue and results in more foreign body reaction.[15]

A consideration of the chemical and physical properties * of these plastics will aid in explaining the results that were obtained. Nylon is a condensation product from which water is expelled upon polymerization.[11,18] It is destroyed by strong acids and poorly resistant to weak acids, hydrolysis being rapid at a pH below 3. Alkaline solutions are hydrolytic at a pH above 8. At elevated temperatures, particularly steam under pressure, the breakdown is rapid.[1,4,11,13,18-20] One would expect hydrolysis to occur when the material is subjected to the body fluids and slightly elevated temperatures over a long period of time. It is also more wettable than any of the materials except polyvinyl sponge.[20] This chemical instability and wettability can explain the greater degree of tissue reaction that is encountered. This also explains a loss of tensile strength after implantation (83% in six months).[9]

Dacron is a polyester and is also the product of a condensation reaction in which water is expelled.[14,18] It has good resistance to mineral acids but is only mildly resistant to alkali.[4,13,18-20] Hydrolysis should occur when it is subjected to the mildly alkaline fluid of the body. It is less wettable than nylon.[20] The slightly greater stability and less wettability may explain the lesser tissue reaction encountered than with nylon. It also loses less strength.[24]

Orlon [11,14,18,20] is a polymer resulting from a direct addition type of reaction; therefore, breakdown should occur less readily. It is, however, attacked by alkali.[4,13,18-20] It is more wettable than Dacron.[20]

Polyvinyl sponge is the least resistant of the materials to acid or alkali and is water-soluble.[14,17,20] Its wettability is evidenced by its use as a sponge. The sinuses in the sponge make it difficult to compare with the other materials. After implantation it is initially surrounded by a fibrous capsule, leaving the sinuses open for the accumulation of trapped serum and breakdown products. This probably accounts for the relatively extreme degree of foreign body reaction in these communicating spaces. That polyvinyl is broken down at a more rapid rate than the other materials is evidenced by extreme friability in the implants and artery grafts and rupture of molded grafts in the thoracic aortas of dogs.[8]

Teflon is the most inert of the plastic materials studied to date.[1,14,20] It is stable against hydrolyzing and oxidizing agents. The wettability is practically nil.[20] These properties explain the slight degree of reaction in the tissue and no loss of strength after implantation for 10 months.[24]

The limitations to the use of Teflon in the past have been due to the inability of the manufacturers to extrude it in the appropriate form. It is now available in several forms, including tubes, film, and a weave. The tubing should be useful for T-tubes where concretions and scarring are big problems. Small sheets should be ideal for drains, particularly in places where the prevention of adhesions is important and where they are to be left for long periods of time. The weave is satisfactory for artery grafts, and the results in this laboratory to date are good.[10] It should offer advantages in the replacement of bone and fascial defects where nylon is now being employed.

Conclusion

Although the response of the hosts to the plastics studied is minimal in comparison with that to such materials as silk, it is incorrect to assume that there is none. The results in this study indicate that from the standpoint of tissue reaction Teflon is a most desirable synthetic material for use in surgery.

* In reviewing the technical literature one finds studies in which each of the synthetics has been subjected to various chemical and physical conditions for short periods of time; however, we were not able to find instances in which they had been subjected to similar conditions for a prolonged period. The statements regarding their breakdown are, therefore, what one might expect in the body, though no actual determinations have been made.

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The Intrathoracic Use of Au^{198} After Pneumonectomy

A Preliminary Study

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Bronchogenic carcinoma is increasing in frequency, and the five-year survival rate following all forms of therapy remains disappointingly low. One of the reasons for this latter situation is the presence of tumor cells in the mediastinal lymph nodes, especially those of the opposite side, not customarily removed even in the "radical" pneumonectomy. In the attempt to deal with these nodes by radiation, it seemed feasible to place a radioactive substance in the empty hemithorax immediately postoperatively, in the hope that the substance would be picked up by the pleural and mediastinal lymphatics and carried to the mediastinal nodes. The obvious choice of a test substance was colloidal Au^{198}, since this substance has been used in the pleural space,[1] delivers 95% short-range (mean penetration 0.38 mm.) beta radiation, and has been shown to be carried to mediastinal nodes after intrabronchial instillation.[2] In addition to intrabronchial and intrapleural administration, Au^{198} has been used intraperitoneally, intrathecally, intravenously, and by direct injection into tumors. Its toxic and radiation hazards in man have, by the intravenous route, been found to be not excessive in doses up to 0.8 to 1.2 mc. per kilogram of body weight. With an intact pericardium, the only new hazard in the proposed postpneumonectomy intrapleural instillation would be the effect on the healing of the sutured hilar structures, particularly the bronchial stump. Consequently, a short series of experiments was done to evaluate bronchial stump healing and to gain initial information concerning nodal uptake of the radioactive substance.

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From the Radioisotope Unit of the Veterans Administration and the Departments of Surgery and Medicine, Medical College of Alabama.

Procedure

Ten adult mongrel dogs, weighing from 6 to 10 kg. each, were used. With sterile technique, a left pneumonectomy was done. The bronchial stump was treated in routine atraumatic fashion, with an end-on closure secured with interrupted nonabsorbable surgical (silk) sutures. Deliberately, however, the bronchial stump was left rather long, was closed with heavy (00) silk, and was not covered with pleura. The raw hilar mediastinal surface was not pleuralized. Postoperatively, the animals were given 300,000 units of penicillin and were fed regular rations ad lib. Sterile saline, 30 cc., was injected into the empty hemithorax, with removal of an equal amount of air. With a shielded syringe, 1 to 4 cc. of radiogold colloid (Aurcoloid*) (specific activity averaging 25 mc/cc.) was injected into the left chest; the dog was returned to his cage, where it was rotated vigorously from side to side and the body was shaken in a see-saw motion to insure spread of Au^{198} over the parietal pleura. In seven animals the Au^{198} was instilled within a few hours after surgery; in two animals, after 24 hours, and in one animal, after 8 days (Table).

All animals were killed (one died) at intervals of 2 to 22 weeks, and autopsies were performed from the right side, in order to avoid, as much as possible, surface contamination of the removed specimens from material in the left chest. Specimens removed consisted of the right paratracheal, right main bronchus, subcarinal, and left main bronchus nodes and biopsy specimens of the trachea, bronchial stump, myocardium, pericardium, aorta, diaphragm, and intercostal muscle. Microscopic sections were made, and in Dogs 6, 7, 8, and 10, radioautographs (RAG) were made of all specimens. Each tissue had several radioautographs made, with exposures up to 16 days.

* Abbott Laboratories. Aurcoloid is radiogold (Au^{198}) colloid, the particles being approximately 0.003μ in diameter. Half-life is 2.69 days, and the radiation consists primarily of a 0.97 mev beta ray and a 0.411 mev gamma component.

Over-All Data on Ten Dogs Given Radioactive Au^{198} Intrapleurally After Left Pneumonectomy

Dog	Date of Surgery	Date & Dose of Au^{198}, Mc.	Disposition & Date	Total Exposure to Au^{198}, Days	Autopsy				
					Bronchial Stump	Lymph Nodes			
						Left Main Bronchial	Carinal	Right Main Bronchial	Right Paratracheal
1	12/21/54	12/29/54 42	3/ 1/55 killed	62	Healed, grossly & microscopically	Marked fibrosis & cell loss	Marked fibrosis & cell loss	Normal	Not found
2	12/29/54	12/29/54 75	1/12/55 killed	14	Healed, grossly & microscopically	Extensive acute necrosis	Extensive acute necrosis	Slight acute necrosis	Normal
3	1/ 6/55	1/ 6/55 75	6/22/55 killed, scrotal & subcutaneous sarcoma	167	Grossly intact, microscopically shows acute inflammation & mucosa loss	Shrunken, mod. fibrosis, mod. cell loss, disrupted over-all pattern	Same	Same	Same
4	1/ 6/55	1/ 6/55 75	3/ 1/55 killed	54	Healed, grossly & microscopically	Slight cell loss	Slight cell loss	Mod. fibrosis, mod. cell loss	Slight cell loss
5	1/12/55	1/12/55 (?) 25	6/21/55 killed	160	Grossly intact, microscopically shows acute inflammation & mucosa loss	Slight cell loss & disrupted pattern, shrunken	Same	Same	Same
6	1/12/55	1/12/55 90	2/ 3/55 killed	22	Healed, grossly & microscopically	Slight cell loss, slight RAG activity	Disrupted pattern, slight RAG* activity	Congestion, disrupted pattern, slight RAG activity	Same
7	1/18/55	1/18/55 75	2/ 3/55 killed	16	Healed, grossly & microscopically	Mild cell loss & congestion, slight RAG activity, disrupted pattern	Marked cell loss & congestion, slight RAG activity, disrupted pattern	Mild cell loss & congestion, slight RAG activity, disrupted pattern	Complete cell loss, mod. RAG activity
8	1/18/55	1/18/55 79	2/17/55 killed	30	Healed, grossly & microscopically	Mod. congestion, mod. cell loss, mod. RAG activity	Extensive cell loss, heavy RAG activity	Mod. congestion, mod. RAG activity	Mod. cell loss, mod. RAG activity
9	1/24/55	1/25/55 75	2/28/55 died, rt. pneumothorax	34	Grossly intact except for tiny air leak at suture hole; end healed microscopically	No marked changes, slight cell loss	Same	Same	Same
10	1/24/55	1/25/55 75	2/ 8/55 killed	14	Healed, grossly & microscopically	Mod. cell loss & disrupted pattern, slight RAG activity	Minimal congestion & cell loss, minimal RAG activity	Mod. cell loss & disrupted pattern, mod. RAG activity	Mod. cell loss & disrupted pattern very heavy RAG activity

* RAG, radioautograph.

Radioactivity measurements were made on the lymph nodes of only one animal, with a scintillation well counter.

Findings

No dogs developed infection. Dog 3 developed scrotal and subcutaneous sarcoma. Dog 9 died 34 days after surgery and instillation of gold. At autopsy there was complete collapse of the right lung. The bronchial stump appeared intact, but underwater test revealed a tiny air-leak at the site of a suture, several millimeters back from the stump end. Grossly and microscopically the stump end was healed. This animal, nevertheless, apparently died from right-sided pneumothorax and atalectasis via a left bronchial leak and a traumatic mediastinal defect. Otherwise, all dogs remained vigorous.

By radioautographs, the colloidal gold appeared to have distributed itself around the empty hemithorax and adhered to all exposed structures. The bronchial stumps shared in the exposure to radiation. In all 10 dogs the bronchial stumps were well healed grossly, including that of Dog 9. Microscopically all were healing or had healed with regeneration of mucosa, without marked deficiency or excess of fibrosis. Inflammation was not a feature, except in long-survival Animals 3 and 5, in which there was marked acute and chronic inflammation of the stump end tissues, next to the lumen, with absence of mucosa.

Pathologic changes in the lymph nodes varied and were not predictable on the basis of the dosage of Au^{198} or the duration of exposure. In general, the short-exposure specimens tended to show congestion, necrosis, and loss of cells. The long-exposure specimens tended to show loss of nodal tissue architecture, some loss of cells, and fibrosis. This latter was especially true in the two long-term-survivor animals, Dogs 3 and 5, whose nodes were shrunken and string-like, in contrast to the large gray succulent nodes found in the other animals. All nodes examined by radioautography showed evidence of the presence of Au^{198}, although the amount of radioactivity varied. A measure of tissue radioactivity in Dog 2 confirmed the impression of heavy irradiation present in these nodes, which microscopically were undergoing necrosis.

Comment

In order to expose these bronchial stumps to radiation and encourage them to break down if they were going to, they were left long, closed with heavy silk, and not pleuralized. Yet, with certain minor discrepancies, they appeared to show a satisfactory healing process. The inflammation in the late survivors may have been due, in part at least, to stagnant infected secretions in the lumen of the stump.

The lymph node studies demonstrated that the radioactive gold is in fact taken up by the mediastinal nodes, even of the opposite side. Radioautographs show this radiation activity to be in the substance of the node and not just surface contamination. The pattern was variable, but the radiation activity, as shown by radioautographs, appeared to be usually heavier in the center of the node than at the periphery. The quantity of radiation delivered to the various nodes was also variable and inconsistent, by radioautography. In some instances, for example, the right paratracheal node showed much more activity than the intervening nodes nearer to the operated on side. Study of the quantity of gold taken up by various nodes and tissues, after intrapleural administration, is the subject of further work currently being done. The microscopic lymph node changes also were variable and unpredictable, and they did not correlate well with radioautograph impressions. It is apparent, however, that tissue irradiation changes occur in these nodes, varying from congestion and minor loss of cell elements up to severe necrosis and destruction of all cells.

The fact that dye injected near certain cancers tends to go to normal nodes and circumvent cancerous nodes[3] mitigates

against the concept that Au^{198} in the pleural space after pneumonectomy may be concentrated in cancerous mediastinal nodes in quantities sufficient to deliver lethal radiation. Nevertheless, since the procedure seems to be safe, and since the Au^{198} does go to the mediastinal nodes, we believe that the method deserves a well-controlled clinical evaluation.

Summary

Au^{198} in doses up to 90 mc., placed in the empty hemithorax of dogs, after left pneumonectomy, is taken up, in unpredictable quantities, by the mediastinal lymph nodes, which show varying degrees of radiation effect. The bronchial stump heals satisfactorily.

The University of Alabama Medical Center (3).

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Case Reports

Sequestration of the Left Lower Lobe of the Lung

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Abnormal lobes of the lung have been recognized in autopsy material for many years. The least common of such abnormal lobes are those known by such synonyms as Rokitansky lobe, extralobar sequestrated lobe, accessory lung, aberrant lobe, and supernumerary lung. Bruwer, Clagett, and McDonald [1] precisely define the abnormality as "an anomalous, nonfunctioning piece of pulmonary tissue . . . found either below the diaphragm or between the diaphragm and the lower lobe . . . . [It] is enclosed in a pleural sheath of its own." Although von Rokitansky * in 1861 was able to find 12 cases in the literature and reported 1 of his own, all were autopsy cases, and the first clinical report did not appear until 1947. In that year Valle and White [3] presented their patient, a 9-month-old boy, with an extralobar sequestrated lobe, who unfortunately died of shock during operation for an associated diaphragmatic hernia. The following year DeBakey, Arey, and Brunazzi [4] successfully excised an accessory sequestrated lower lobe from the left pleural cavity of a 7-year-old girl. In each of these cases the sequestrated lung tissue was in addition to the normal complement of lung tissue on the affected side. Recently a case of pulmonary sequestration has been seen wherein the sequestrated portion was actually the entire lower lobe. The details are as follows:

Report of Case

A male child weighing 2730 gm. was born after 8 months' gestation. No untoward incidents occurred during the pregnancy. The mother, aged 21 years, and the father, aged 25 years, were in excellent health. There was one sibling, aged 20 months, who was normal. Immediately after birth the patient cried lustily and was of good color. About an hour later it was observed that he was slightly cyanotic and that his breathing was labored. Auscultation of the chest now revealed that aeration in the left lower lung field was impaired. A mucolytic aerosol (Alevaire) mist with oxygen was administered, with slight improvement in color, but he did not become "pink." An x-ray demonstrated a density in the left lower chest, with shifting of the mediastinum to the right (Fig. 1). The density was thought most likely to be a bronchogenic cyst. Surgical consultation was obtained, in view of the continued cyanosis and x-ray findings. Examination at this time revealed an infant weighing 2550 gm., with

Fig. 1.—Preoperative radiogram of chest, showing density in left lower thorax and shifting of mediastinum to the right. (Lateral film was not of reproducible quality; it showed the density to be the same shape as a normal left lower lobe.)

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From the Surgical and Pediatric Services, Moses H. Cone Memorial Hospital.

* Reference 2, cited by Freedlander and Gebauer.[6]

a pulse rate of 138 per minute, respiratory rate of 40 per minute, and rectal temperature of 99.4 F. The skin was slightly cyanotic. No abnormality was noted of the head or neck. The chest was asymmetrical, and there were diminution in size, inspiratory retraction, and absent breath sounds in the left lower part of the chest. The heart was shifted to the right, with the point of maximal impulse just barely to the left of the sternum. No murmurs were present. Remainder of examination did not reveal any abnormality.

It was evident that the child had a physical abnormality consisting of a space-occupying lesion in the left lower thorax. It was most improbable that improvement could occur spontaneously; therefore, exploratory thoracotomy was recommended to and accepted by the family.

In preparation for the operation 1 unit (500 cc.) of whole blood was cross matched and a Levin tube was inserted into the stomach. The baby was anesthetized with cyclopropane, with an endotracheal tube subsequently being inserted. The left eighth interspace was opened laterally. No adhesions were present; the left lower lobe appeared atelectatic. Palpation revealed this lobe to be very heavy and not attached at the hilus. An artery and vein pierced the dome of the left half of the diaphragm and entered the lower, or diaphragmatic, surface of the mass. This vascular pedicle was doubly ligated and divided, and the mass was removed. The upper lobe, with its easily identifiable lingula segments, was of normal size and shape and expanded well. The wound was closed in layers, and a small catheter was left in the pleural space for drainage.

Postoperatively there was no further cyanosis. The baby took feedings avidly. The chest catheter was removed after x-rays on the second postoperative day showed that there was no air or fluid in the left hemithorax, the mediastinum had shifted to the left, and the upper lobe had expanded to fill the pleural space completely (Fig. 2). The child was discharged on the sixth postoperative day and remains in excellent health 18 months later.

Pathological Report.—Gross Description: Received fresh is a pyramidal-shaped specimen measuring 6.5×6×4 cm., which weighs 30 gm. and sinks in water. Its lower margins are sharp, similar to those of a lower pulmonary lobe. There is a reticular pattern of gray streaks on the surface and a distinct subdivision into lobules. At the lower posterior margin there is a clamped pedicle. After fixation the specimen was cut in a plane directly perpendicular to the insertion of the pedicle. In the pedicle and extending inward are vessels containing blood and also thin-walled channels that are free of blood. The substance of the specimen is reddish-brown and is generally subdivided into lobules in a manner closely similar to that of normal lung tissue. However, immediately adjacent to the pedicle is a focus measuring 2×1×1 cm. of compact light-grayish-yellow tissue.

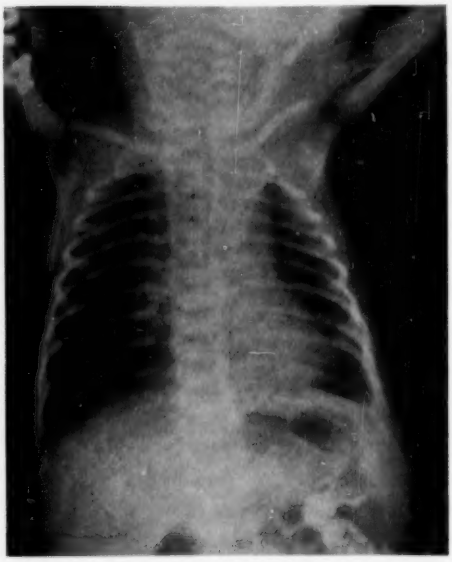

Fig. 2.—Radiogram taken 48 hours postoperatively. Notice complete expansion of upper lobe, with shifting of mediastinum to the left.

Microscopic Description: At the hilus there are vessels, bronchi, lymph nodes, and nerves. The blood vessels have the structure of pulmonary arteries (elastic rather than muscular wall). The bronchi have muscular and cartilaginous components and a normal epithelium (Fig. 3). For the most part the structure of the remainder of the specimen is that of an ordinary lung except in the gray compact focus seen grossly. Here there are but few air sacs and many irregular spaces lined by bronchial epithelium and separated by broad bands of connective tissue (Fig. 4).

Diagnosis: (1) Congenital sequestration of lower portion of left lung; (2) focal dysplasia of lung.

Comment

There are many theories on the mode of formation of pulmonary sequestration abnormalities. Davies and Gunz [5] have published an excellent paper discussing the various theories and have come to the conclusion that the abnormalities must originate very early in embryonic life, possibly at the 17 somites stage. They believe that

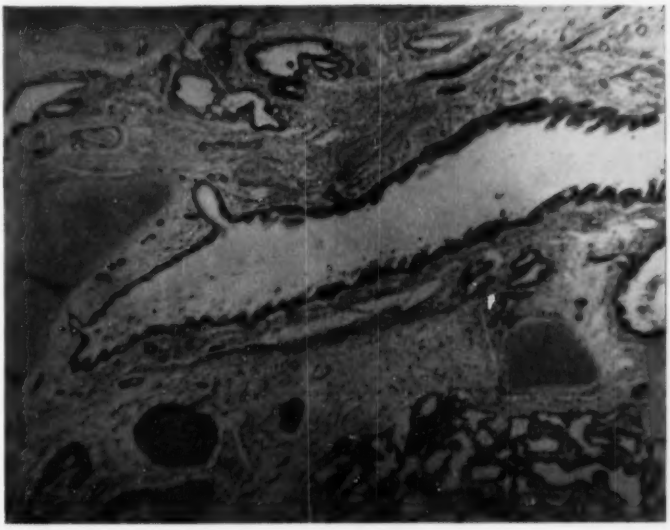

Fig. 3. — Photomicrograph of the tissue at the hilum of the sequestrated lobe, showing a normal bronchus with cartilage, as well as lymphatic tissue, blood vessels, nerves, and normal pulmonary tissue.

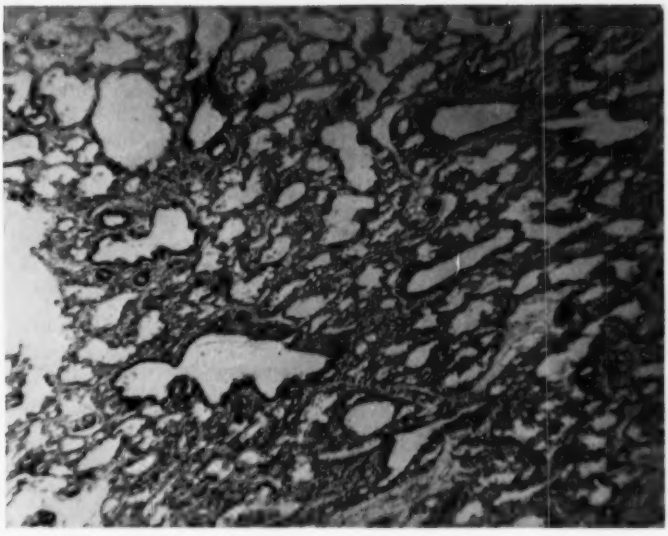

Fig. 4.—Photomicrograph showing the area of focal dysplasia (see text for description).

sequestration begins when the unpaired analage of the lungs separates from the hepatic bud and the esophagus. Thus, a portion of the lung, if attached to the stomach analage, would migrate caudally with it. Commonly, the remaining lung would develop normally. Hypothetically, if the separation occurred late, the forerunner of a specific lobe might become sequestrated to produce the result seen in the case being reported. Cockayne and Gladstone [6] believe that anomalous accessory lobes result from adhesions forming between the growing lung bud and the coelomic epithelium, with resultant separation of a part of the lung bud. Such a theory is also compatible with what was found in the case being reported.

The presenting symptoms in this newborn child probably resulted from involvement of the entire lobe and shifting of the mediastinum to the contralateral side, in-

asmuch as such lesions are generally asymptomatic and are usually found only incidently. Boyd [7] has even said, "Extralobar sequestration is usually an autopsy diagnosis, and rather likely to remain one." Freedlander and Gebauer [8] similarly state "Accessory (intralobar sequestrated) lobes and agenesis can be distinguished by the roentgenogram, but aberrant (extralobar sequestrated) lobes have no known typical picture unless they contain much fluid or are altered by disease." This is so because the majority of such lesions are too small to produce active interference with the ventilatory process. In Valle and White's [3] case, the sequestrated lung was found during operation to correct a congenital diaphragmatic hernia. In DeBakey, Arey, and Brunazzi's [4] case, what was thought to be a large cyst was noted on a chest x-ray taken because the patient had a cold and was suspected of having pneumonia.

The treatment of a sequestrated lobe of the lung, be it intralobar or extralobar, is surgical. Infection is inevitable, even if the lobe is so small that it does not interfere with normal ventilation. It is interesting to note that Davies and Gunz,[5] in summarizing the literature, found that accessory lobes were subject to the same diseases as normal lung tissue. Also, since the preoperative diagnosis of extralobar sequestrated lobe seems rather unlikely, in view of the lack of any absolute diagnostic signs, surgery becomes indicated as a diagnostic procedure.

Summary

Successful treatment of sequestration of the entire left lower lobe in a newborn child is reported. This is apparently the first time sequestration of an entire lower lobe has been reported, and the patient is the youngest one to be operated on for any type of sequestration.

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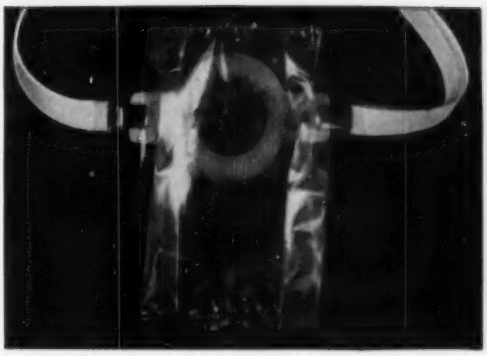

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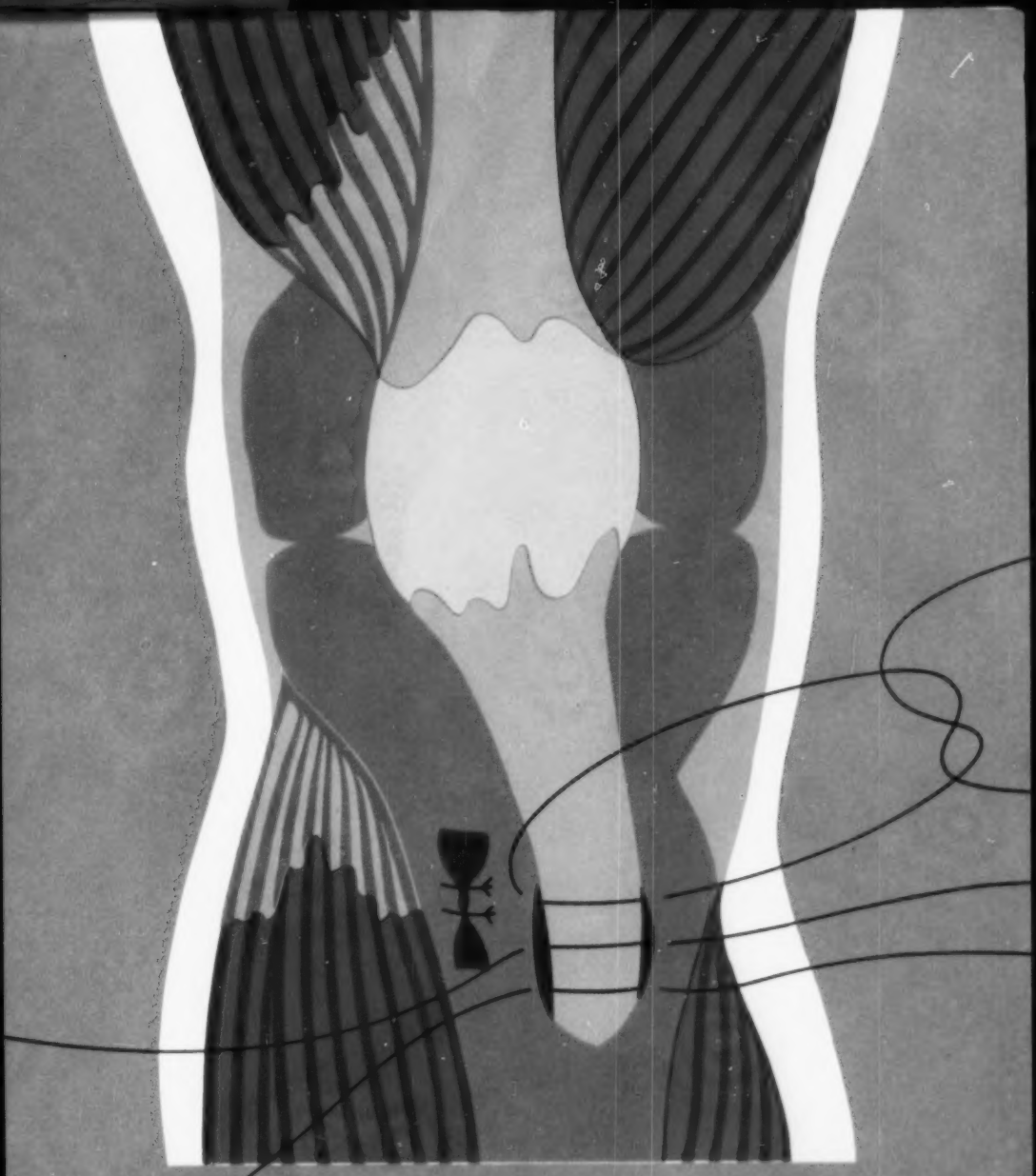

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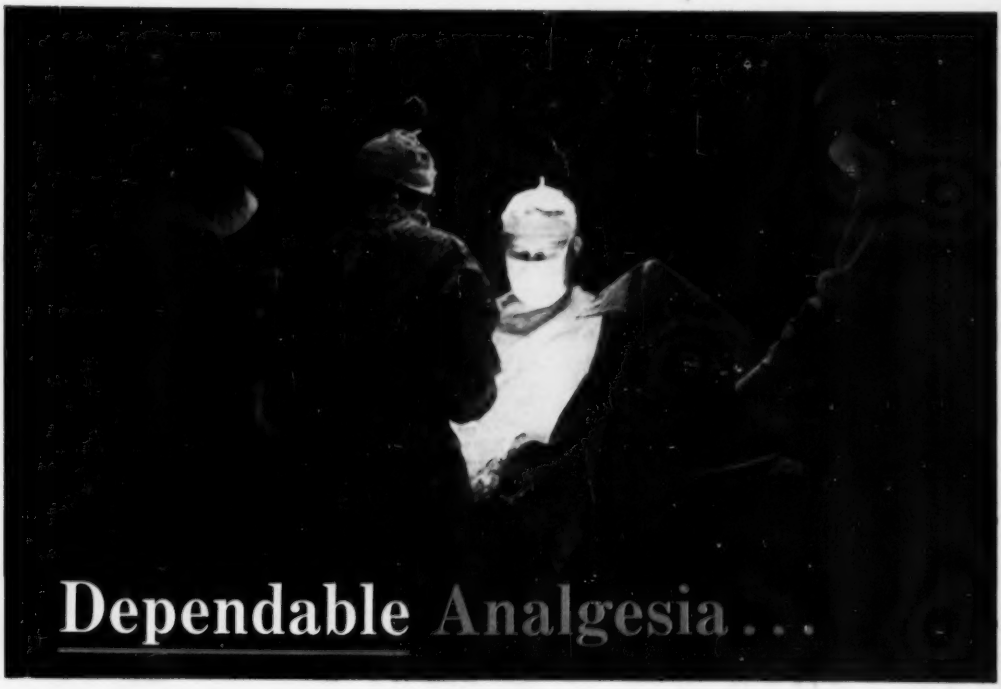

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